TEN-TEC MODELS 247 & 277 ANTENNA TUNERS

GENERAL

Models 247 and 277 Antenna Tuners are inductive/capacitive networks used for matching unbalanced 50-75 ohm output impedances of transmitters and transceivers to a variety of loads, both balanced and unbalanced. They operate over a frequency range of 1.8 to 30 MHz. Both incorporate the universal Transmatch circuit. Model 277 has, in addition to the tuner components, a built-in SWR bridge and meter.

SPECIFICATIONS

Circuit: Universal Transmatch.
Rf Power: 100 watts, continuous: 200 watts, intermittent.
Capacitor Voltage Rating: 1 kV.
Toroid: 47 tap, 18 guage silver plated wire on 2" diameter core.
Input Impedance: 50-75 ohms.
Output: Matches all loads, balanced and unbalanced. Maximum balanced load 1.8 to 4.0 MHz is 600 ohms.
Frequency Range: 1.8 to 30 MHz.

Model 247 Only:

Finish: Etched aluminum chassis and front panel; black textured sides and top.
Size: HWD 2-15/16" x 7-3/4" x 6-11/16".
Weight: 3 lbs.

Model 277 Only:

Meter: SWR bridge with forward/reverse switch.
Finish: Grey chassis and front panel; black textured sides and top.
Size: HWD 3-1/2" x 10-1/4" x 6-1/2".
Weight: 3 lbs.

INSTALLATION

1.) Connect coaxial output of transmitter to coaxial input of tuner with short length of RG-8 or RG-58 cable. Connectors are PL-259 types. Notice: To reduce possibility of rf from getting into transmitter, position tuner as far away from transmitter as is practical. Never set tuner directly on top of transmitter.

2.) Connect station ground buss to terminal on tuner marked GND with heavy metalic braid or wire. This lead should go directly to the earth ground system with as short a lead as possible.

3.) Connect transmission line to appropiate terminals on tuner as follows:

A.) For unbalanced transmission lines, use connector labeled COAX and coaxial type cable. Do not connect jumper between SINGLE WIRE and one BALANCED LINE terminal.

B.) For single wire feeds, connect line to SINGLE WIRE terminal.

C.) For balanced line feed systems, first jumper terminals indicated, SINGLE WIRE and one BALANCED LINE, with short wire. Connect feed line to two BALANCED LINE terminals.

In both single wire and balanced line systems, take special care to route transmission line as far away from station equipment as possible. Never drape lines over transmitter. These lines may have a high voltage point inside the shack which presents high rf fields.

4.) If your tuner is Model 247 and no bridge is incorporated in the transmitter, insert a SWR bridge in series with the lead between transmitter output and tuner input. Do not place bridge in output line of tuner. SWR bridge is necessary for proper tuner adjustment. (When using Model 240 One Sixty Converter with TEN-TEC Models 540/544 tranceiver, SWR bridge in transceiver cannot be used on 160 meter band for tuner adjustment. Either Model 277 with SWR bridge incorporated or a separate bridge inserted in line between Model 240 output and antenna tuner input must be used.)

ANTENNA SYSTEMS MATCHING THEORY

Most transmitters are designed to work into a 50-75 ohm resistive load, and they are not able to effectively supply rf power to loads that depart far from these values. However, many antenna systems, which include the antenna and the transmission line, have complex impedances that make it difficult if not impossible to load the transmitter properly. These impedances are a function of the operating frequency, type of antenna, type and length of transmission line, height of antenna and its proximity to other objects.

Models 247/277 provide a coupling method to convert the resistive/reactive load to a pure resistance of 50 ohms that will accept maximum power from the transmitter. This is not to say that any and all antennas, when converted to a 50 ohm resistive impedance by means of a tuner, will give identical performance. To best understand the tuner adjustments required, it is necessary to have a fundamental knowledge of how antenna systems function. To this end, a short technical discussion follows. It is recommended that additional reading on the subject be made by those interested in obtaining maximum performance from their antenna systems. The ARRL Antenna Handbook, ARRL Amateur's Radio Handbook (antenna and transmission line sections) and other antenna books published by the publishers of Amateur Radio magazines are excellent sources of information. For those already versed in antenna theory, skip down to the OPERATION section.

THE ANTENNA - Any conductor that has rf currents flowing in it can be looked on as an antenna or radiator. The extent to which power leaves the conductor and radiates into the surrounding medium depends on many factors -- length, frequency, amount of current, configuration, etc. Since the antenna absorbs power from the device feeding it, it can be replaced with a resistance whose value is such that the power delivered to this resistance is the same as that delivered to the antenna. The value of this resistance is now a measure of the radiating effectiveness of the antenna and is termed "radiation resistance". For a given value of antenna current, the higher this resistance, the more power that is radiated. ($P=I^2R$)

Due to the facts that an antenna has physical length, that currents travel at a velocity less than instantaneous and that the conductor posseses a certain amount of self inductance and capacitance, the current at the feed point may not be in phase with the voltage at this point. As a result, the impedance at this point may not look like the pure resistance first suspected, but as an impedance consisting of resistance and either inductive or capacitive reactance. This added reactance will limit the amount of current supplied to the antenna for a given voltage, and therefore reduce the amount of radiated power. The reactance does not absorb power in itself -- only a resistance can do that -- but its presence reduces the overall radiated power and antenna current.

There are two ways to restore the power to its non-reactive value. The first, which is not the preferred way because it does not maximize power transfer, is to raise the feed pcint voltage enough so that the current returns to its original value. The second, and preferred method, is to add a reactance in series, equal in value but opposite in type (sign) to the reactance value of the antenna. For example, if the antenna at the operating frequency presents an inductive reactance of 100 ohms (+j100) along with a resistance of 50 ohms, inserting a capacitor whose reactance is also 100 ohms (-j100) in series has the effect of cancelling out the reactance of the antenna, leaving only the 50 ohms resistive. This can be looked on as a series R,L,C circuit that is in resonance, whose total impedance is only that of the resistance. Another term for this approach to maximize power transfer is "conjugate impedance matching".

In the above example, we used a value of 50 ohms for the radiation resistance. If this value were not 50 but 150 ohms, the impedance after cancelling the reactance out would be 150 ohms. Connecting this load to the transmitterdesigned to operate with 50 ohms load would not result in optimum power transfer. It would, however, be better than leaving the inductive reactance in, since the antenna current is maximized for the conditions that do exist. To obtain design performance, it is necessary to transform the 150 ohms to 50. This can be done with a transformer with a turns ratio of 1.73 to 1. (Impedance transformation is equal to the square of the turns ratio.) It is also possible to accomplish this transformation with a parallel tuned circuit with primary and secondary taps properly located on the inductor, or using two or more capacitors in series with taps taken from the series string. Under these conditions, the transceiver will deliver rated power to the antenna.

One last observation before we go on. The antenna impedance in the above example was stated as that at the feed point. If we now feed the antenna at a different location along the conductor, the impedance will be different, both resistive and reactive components. There are an infinite number of impedance choices available, depending on where the tap is made. This factor is helpful in designing and matching antennas. The factors that determine this impedance are the current and voltage values at this point, and the phase between them.

THE TRANSMISSION LINE - In the above example, we assumed that the transmitter output was connected directly to the feed point. This is hardly practical. So that the transmitter can be located at a distance from the antenna, we use a transmission line to deliver the power. Unless we have a perfectly matched system, i.e. antenna, line and transmitter output impedances all the same value without reactive components, the addition of the transmission line completely changes the picture. The transmitter will not see the antenna impedance of 50 ohms resistive and 100 ohms inductive reactance, but some other combination. It will depend on the electrical length of the line, its characteristic impedance and frequency. The impedance at the transmitter end is what we are interested in, and the inductive component may even be changed to capacitance. (Only when the electrical length of the line is an exact multiple of the half wavelength will the impedance at the transmitter be the same as the antenna impedance.)

Briefly, the line characteristic impedance is determined by the physical dimensions of the line -- wire diameter and spacing -- and the dielectric of the material in between. The wire also posseses a resistive component which will dissipate power when current flows through it to the antenna. This shows up as heat loss and dictates use of low loss cable. Formulas for coax and open wire line impedances are given in the handbooks.

Since rf currents flow in the transmission line, one may ask if it then becomes an antenna. In the case of coax type lines, the current should flow on the inside surface of the outer conductor and outer surface of the inner conductor. The electric and magnetic fields caused by the current flow are confined between the two, so none can escape and be radiated. If a system configuration results in some rf current flowing on the outer surface of the outer conductor, such as when a dipole is fed with coax without a balun or other means of changing the feed line from an unbalanced to balanced configuration, it will radiate power. In the case of parallel lines, the current in one conductor at a given location should be flowing in the opposite direction to the current in the adjacent conductor, and if the system is well balanced, the amplitudes of the two will be equal. Under these conditions, the two sets of fields exactly cancel each other and very little radiation will result. If the two currents are not equal or not in exact opposite phase, there will be radiation. Also, if the spacing between lines is a considerable portion of the wavelength, radiation will occur. This is not a factor below VHF.

One final characteristic of transmission lines should be mentioned. The rf current flowing in the line travels at a speed less than that of radiated power in a vacuum, or the speed of light, both 186,000 miles per second. This slowing is caused by the dielectric property of the medium through which the field traverses. In coax cables it is polyethelene between inner and outer conductors, and in parallel lines, it may be the plastic between the conductors in the case of twin-lead type line, or the air and plastic spacers in open wire

types. The ratio of the speed in the line to the speed in a vacuum (air is almost the same) is called the velocity factor of the cable. It is always less than unity. Because of this slowing, the physical length of a transmission line is not the same as the electrical length. For example, the wavelength in free space of a 30 MHz signal is exactly 10 meters. A transmission line 10 meters long will be one full wavelength only if the dielectric between the conductors is air. In the case of coax cable with polyethelene dielectric, the velocity factor runs about 0.67. The same 10 meter length of cable will now appear electrically as an open wire or air dielectric cable 15 meters long (10 divided by 0.67). This is equivalent to one and one half wavelengths. A polyethelene type cable would only have to be 6.7 meters long to be one wavelength.

EFFECT OF TRANSMISSION LINE ON ANTENNA IMPEDANCE - As a result of all of the above, in situations where we do not have a matched system throughout, and this is most of the time, the impedance presented to the transmission line by the antenna sets up standing waves on the line. These standing waves will alter the antenna impedance all along the line toward the transmitter. What we really want to accomplish with the antenna tuner is to take whatever impedance that is established at the transmitter end of the line and alter it to a 50 ohm resistance. Then the transmitter will be happy, at least. The tuner will not affect the mismatch of antenna to line -- only constructing the antenna differently will do that --nor eliminate a standing wave on the transmission line. It will eliminate a standing wave on the line between transmitter and tuner input, but not on the output side of the tuner. A good antenna is still needed to "get out". If the antenna has a low resistance, the tuner will transform it, along with the cable loss resistance, to 50 ohms. The full power will enter the system, but it will be divided between radiation and cable heat loss. It is not uncommon that more than half of the available power is wasted in cable losses, even with low loss cable. It just gets a bit hotter. The split depends entirely on the ratio of radiation resistance to loss resistance.

What is the impedance established at the transmitter end of the line? It depends first on the antenna impedance, which is then transformed by the line. This transformation is dependent on frequency, electrical length of the line and the loss in the line. In an Amateur setup where many different frequencies are used with the same antenna, there will be a multitude of impedances presented to the tuner, so adjustment of the matching network will be required as frequency is changed.

STANDING WAVE RATIO - A measure of how badly a system is mismatched is given by the standing wave ratio (SWR) on the line. SWR is the ratio of the maximum voltage encountered along a transmission line greater than one half wavelength long to the minimum voltage. It is also the ratio of maximum to minimum current. The more nearly uniform the voltage distribution along the line, the closer matched it is, and the ultimate is when the voltage is constant down the length of a lossless line, or drops slowly and uniformly along a line with losses. This is the matched condition, represented by a 1 to 1 SWR. The impedance at the load end of such a line is the same as that at the generator end. When adjusting a matching network properly, the way to do it is to observe the SWR and tune for as low a ratio as possible.

The SWR is also an indication of the value of resistance at the load end. The ratio is the same as the ratio of load resistance to line characteristic impedance. This ratio can mean that the load is either greater than or less than the line's impedance. For example, if the SWR on a length of 50 ohm line is 3 to 1, the load resistance is either 150 ohms or 16.7 ohms (3 times 50 or one third of 50). This is only accurate with pure resistive loads.

It can be shown mathematically that a 2 to 1 SWR in a system which has the transmitter output impedance equal to the line impedance delivers 89% of the power to the load that it would if perfectly matched. This relates to a power loss of half a decibel -- hardly noticeable in signal strength. At a 3 to 1 ratio, the loss becomes appreciable with 25% of the power lost. So in adjusting antenna tuners, it is a nice feeling if you achieve a 1 to 1 match, but in reality, anything below 2 to 1 is satisfactory. Line losses do increase a bit also with increasing SWR, but it is still a small fraction of a dB at 2:1.

TRANSMATCH TUNER CIRCUIT - A look at the schematic reveals that the circuit used in TEN-TEC tuners consists of a parallel circuit of inductor L1 and two variable capacitors connected in series. The input is applied to the center of the series capacitors and ground. Another variable capacitor is connected in series with the output lead to the COAX and SINGLE WIRE terminals. For ballanced outputs, balun L2 is connected so that the basic tuner output is applied to one half of the winding, and transformer action produces the opposite half with reference to chassis ground. Hence the balanced output will provide twice the rf voltage, symetrical to ground. The impedance transformation with this arrangement is a step-up of four times on the antenna side. This circuit should match just about any antenna system impedance to 50 ohms.

When the circuit is tuned for a match, the parallel tuned circuit will be approximately in resonance at the frequency involved. Reactive components in the load will be compensated for by both the series output capacitor and a slight off-resonance setting of the parallel circuit. It will be noted that since both inductor and shunt capacitor are variable, there are many possible settings of these components that will resonate at a given frequency. A high inductance with small capacitance will resonate just as well as a small inductance with large capacitor. Is one way better than the other? The answer is yes. When matching to high impedances, there must be a certain amount of inductance present before a match is achievable. The step up transformation of resistance is dependent on the "Q" of the circuit, which is a function of the inductance. In addition, the frequency range over which operation with acceptable SWR is possible without retuning is dependent on the L to C ratio of the circuit. The smaller this ratio, the greater the bandwidth. (To illustrate how effective this becomes at low frequencies, the following results from lab tests at 3.75 MHz and a 50 ohm load were obtained: With maximum L/C ratio, i.e. INDUCTANCE setting of 47 and SHUNT CAP. about 3.2, the frequency range before a SWR of 2 to 1 was encountered was 50 kHz, $\pm$ 25 kHz on either side of the center frequency. Using the lowest L/C ratio, INDUCTANCE set to 14 and SHUNT CAP. to 10, range increased to over 400 kHz, almost the entire 80 meter band.) With the broader band L/C ratio, tuner adjustments become less critical and the SWR meter dip to 1 to 1 is broad. With high L/C ratios, the dip is very narrow and sharp, and it may be easily overlooked.

To summarize the above: Best and broadest operation is obtained when SHUNT CAP. is set to maximum possible setting that will allow a match to 1 to 1. Under these conditions, INDUCTANCE will be minimum at which resonance can be attained. SERIES CAP. is primarily used when reactive components need cancelling out. With single wire resistive antenna, SERIES CAP. setting will be near maximum.

OVERALL SUMMARY

1.) Any antenna can be represented as an equivalent resistive/reactive impedance whose resistive component, termed radiation resistance, is a measure of the power radiated. Reactance can be either inductive or capacitive.

2.) Antenna impedance is a function of frequency, configuration, selection of feed point location, height above ground and nearness to surrounding objects.

3.) The reactive portion of the impedance does not absorb power but limits the amount of power radiated by the resistive component. It is best to eliminate the reactive component, by inserting an equal value reactance in series, but of the opposite type.

4.) Best system performance is attained when antenna impedance is purely resistive with value equal to transmission line impedance, which in turn equals transmitter output impedance.

5.) Since antennas seldom present matched impedances to line over a band of frequencies and from band to band, a partial solution to using these mismatched systems is to convert the impedances at the transmitter end of the line to what the transmitter is designed for, with an antenna tuner.

6.) The transmission line will change the antenna impedance in both resistive and reactive values at the transmitter end, depending on the line's

electrical length, frequency and characteristic impedance.

7.) Due to slowing down of the current flow in the transmission line from that in free space, the electrical length of a line will be longer than the physical length.

8.) One special situation where the line does not alter the impedance is when its length is an exact multiple of the electrical have wavelength.

9.) An antenna tuner will not affect the antenna impedance nor the standing wave condition on the transmission line. It will correct the SWR on that portion of the line between transmitter output and tuner input, so that the transmitter will supply rated power to the system.

10.) Standing wave ratio, SWR, is a measure of the mis-match of the system and is used as the indicator when making tuner adjustments. SWR is direct ratio ofload resistance to line's characteristic impedance.

11.) SWR other than 1 to 1 indicates two possible impedances, one greater and one less than characteristic impedance.

12.) Any SWR value less than 2 to 1 is considered a good match.

13.) Transmatch tuner circuit can provide a number of different control settings, all of which produce a match. Difference is in L to C ratio of the tuned circuit.

14.) The lowest L/C ratio will provide greatest bandwidth for a given SWR limit. If adjusted for maximum bandwidth, retuning across the band will only be necessary on 160 and 80 meters, and possibly on extremes of 40 meter band.

OPERATION

1.) Always make tuner adjustments with minimum required power from transmitter. To do this, set sensitivity of SWR bridge to maximum, fully CW on Model 277.

2.) Set up meter to read SWR. This is REV. switch position on Model 277.

3.) Set both SERIES CAP. and SHUNT CAP. fully clockwise, (10 position).

4.) Apply just enough drive to transmitter so that meter reading is approximately half scale.

5.) Attempt to find a null as INDUCTANCE control is increased from full CCW position. Null may not be deep at this point. If null is not apparent, reduce setting of SERIES CAP. a bit and try again.

6.) With INDUCTANCE set for best null, try to deepen null with SERIES CAP. If rotating this control CCW from 10 position causes meter deflection to increase, set INDUCTANCE control one step clockwise and try dipping with SHUNT CAP. again. Continue until SHUNT CAP. can provide a null near its full maximum position. Adjust transmitter drive to provide adequate meter deflection.

7.) If null produced is not 1 to 1 with rated drive, decrease setting of SERIES CAP. a bit and renull with SHUNT CAP. Continue this procedure until 1 to 1 reading is obtained with full drive, or best null below 2 to 1 is attained. (If by decreasing SERIES CAP. resonance is not attainable with SHUNT CAP., increase INDUCTANCE one more notch and retune capacitors.

8.) To accurately determine if SWR is sufficientle low, set FWD. meter deflection to indexed mark on meter with SENSITIVITY control and read SWR in REV. switch position. Reading below 2 is acceptable.

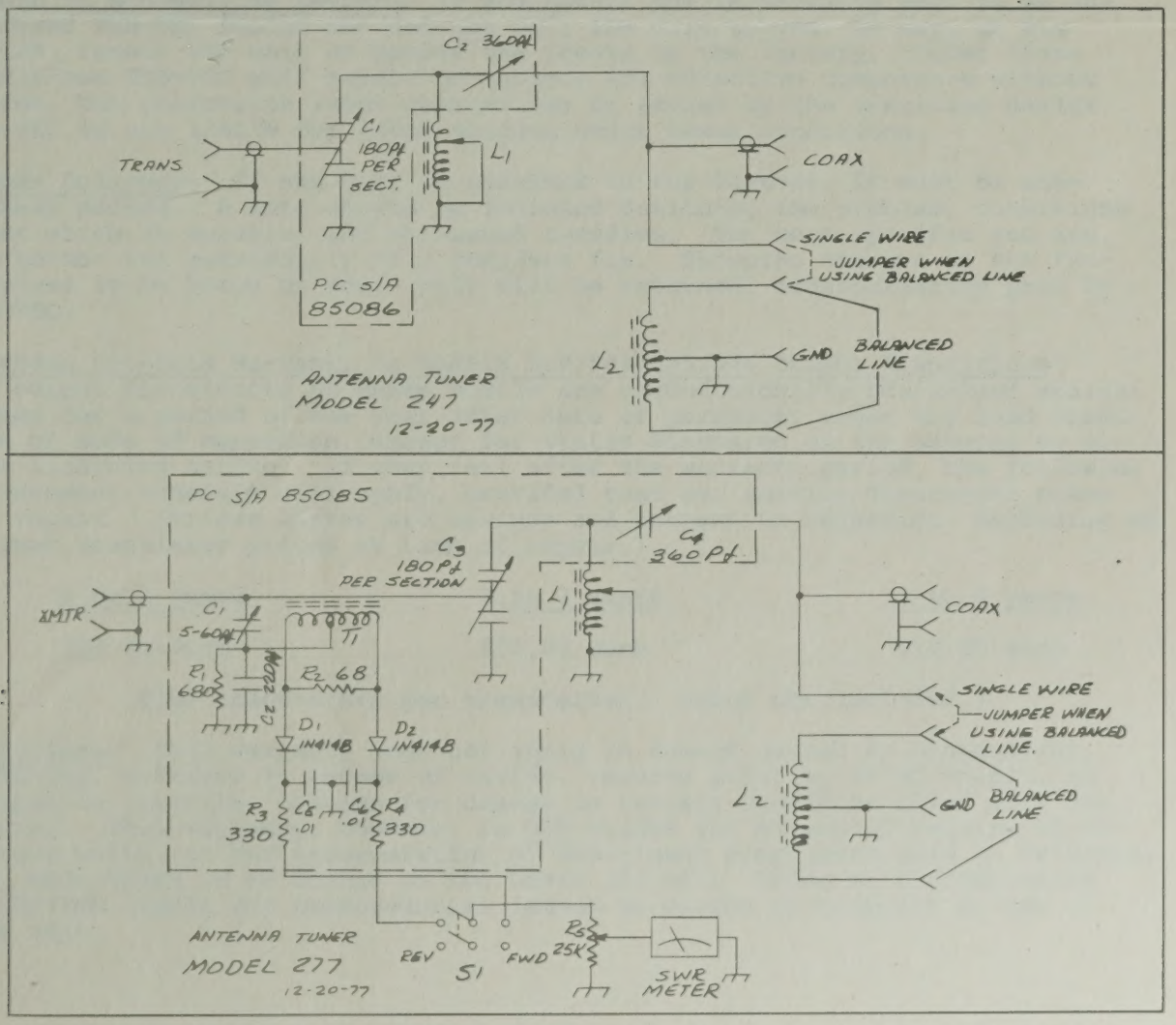
9.) It is good procedure to leave SWR meter in REV. position so that you can monitor match while operating. If you tune too far from resonance, it will be apparent and retuning can be initiated.

10.) It is convenient to record control settings for each band of operation and possibly at 3.6 and 3.9 MHz of 80 meter band. Then tune-up will be simplified when changing bands because starting points will already be established.

Approximate starting points for control settings for each band are given in Table I below. These guideline settings require some alteration for your specific antenna systems, and exact settings should be determined using the procedures outlined above. Reactive loads will alter the values somewhat, but mainly in the SERIES CAP. columns.

TABLE I
GUIDELINE CONTROL SETTINGS

FREQ. MHz	UNBALANCED COAXIAL FEED SYSTEMS									SINGLE WIRE			BALANCED LINE		
	50 OHMS			150 OHMS			17 OHMS			800 OHMS			300 OHMS		
	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.
1.8	7	10	38	7	10	44	10	10	29	-	-	-	8	10	34
3.6	7	10	15	7	10	17	9	10	11	10	10	23	6	10	16
3.9	7	10	13	7	10	15	9	10	10	10	10	21	6	10	14
7.1	6	10	6	7	9	7	7	10	5	10	7	12	5	10	7
14.2	4	9	3	6	7	3	4	10	2	10	5	6	4	10	3
21.2	2	8	2	5	9	1	1	7	2	10	3	4	3	7	2
28.5	1	7	1	2	5	1	0	9	1	10	2	3	3	7	1



TEN-TEC, INC.
Sevierville, TN 37862

REPAIR DEPARTMENT TELEPHONE
615-428-0364

LIMITED WARRANTY AND SERVICE POLICY

TEN-TEC, INC. warrants all products to be free from defects in material and workmanship for a period of one year after date of purchase, under these conditions:

1.) Registration: The warranty card must be returned promptly to establish the warranty period. Our card file also serves as a check on stolen equipment which may be sent in for repair. Please notify us immediately if your TEN-TEC equpment is stolen.

2.) Original Purchaser: This warranty applies only to the original purchaser. Your returned warranty card listing from whom purchased establishes you as the original purchaser.

3.) Communication with the Factory: If trouble develops, contact your TEN-TEC dealer from whom you purchased the unit. He is obligated to try to correct the malfunction or return the unit to us. If he is unable to correct the fault, you or the dealer should contact the factory by mail or by telephone 615-428-0364, giving serial number if assigned, symptoms of fault and conditions under which they appear. You will be advised whether to return the unit to us or to try a replacement plug-in assembly that will be sent to you. To facilitate service calls, please use our direct Repair Department telephone number, 615-428-0364. (NO COLLECT CALLS, PLEASE.)

4.) In-Warranty Field Repairs: To expedite repairs TEN-TEC will send replacement assemblies prior to receiving the suspected defective one from you. The replacement will be billed on a 30 day memo, and credit will be issued when the defective unit is returned to us. No remittance or deposit is required. If the defective assembly is not returned within 30 days, you will be billed.

5.) Return to Non-Selling Dealer: If you return the in-warranty unit to an authorized TEN-TEC dealer who did not sell the unit to you, he may, at his option, repair the unit or handle the return to the factory. Under these conditions TEN-TEC will repair or replace all defective components without charge, but reasonable labor charges may be levied by the servicing dealer. TEN-TEC is not liable for labor charges under these conditions.

6.) Proper Delivery: If the unit is returned to the factory, it must be adequately packed. A note should be included outlining the problem, conditions under which it appears, and attempted remedies. The more specific you are, the better the possibility of a complete fix. Shipping charges to the factory are to be borne by you. Unit will be returned, transportation paid by TEN-TEC.

7.) Extended Pro-Rata Warranty on Models 540/544/545/546 Output Transistors: The output transistors on these models are unconditionally guaranteed against damage for a period of one year after date of purchase, under any load condition or mode of operation, except for static discharge on the antenna or direct lightning strike. If they fail after the warranty period, the following replacement schedule will apply, provided that our service department makes the repair. (Prices listed are maximum and subject to reduction, depending on current transistor prices at time of repair.)

1 to 2 years	2 to 3 years	3 to 5 years
$12.00 each	$15.00 each	$18.00 each

(Two transistors per transceiver. Labor not included.)

8.) Exclusions: This warranty does not apply to damage caused by mishandling, lightning, voltages in excess of rating, reverse polarity of DC supply, or changes in circuits. Claims for damage in transit should be filed with the carrier. This warranty, however, is NOT voided for attempted repairs of defective units, or for incorporation of additional components such as switches, etc. when there is no change in the basic circuit. Under no circumstances is TEN-TEC liable for consequential damage to person or property by use of this unit.

9.) TEN-TEC reserves the right to make any improvements to its products which it may deem desirable without obligating itself to install such improvements in its previously manufactured products.

10.) This warranty is given in lieu of any other warranty expressed or implied.

Out-of-Warranty Repairs

1.) Field Repairs: New circuit boards or discrete components can often be supplied to eliminate the cost and bother of shipping the complete unit to us. A nominal charge will be made for the material sent. Certain assemblies intregal with the main chassis, such as VFO assemblies and rack tuning mechanisms, are not field replaceable.

2.) Returned Units: Along with the unit, please submit a complete report on the nature of the malfunction and the conditions under which it occurs. This will enable our service department to pay special attention to your problem area and reduce overall labor costs. No matter what the malfunction is, every unit will be given a complete alignment and operational check before being returned.

3.) Quotations: Quotations on repair work will be given on request, after examination of the unit. The amount quoted will be firm for the specific work outlined in the quotation. Should additional material or labor requirements come to light after the repair is initiated, you will be contacted for approval before this phase of the repair is started.

4.) Repair Charge Payment: Charges below the $25.00 level will be billed to you after completion of the work and at the time of re-shipment. A report of all work done and parts used will accompany the bill. For charges greater than $25.00, prepayment will be required before the unit is returned. One of three methods of payment may be selected. 1.) Upon completion of the work the billing will be made but the unit will be held here. Upon receipt of the payment, the unit will be shipped. 2.) The unit will be returned to you on a COD basis, with COD charges borne by you. 3.) The repair charges may be paid by either MasterCharge or BankAmericard/VISA.

Approval for COD or charge card options can be given either at the time the unit is submitted to us (in the accompanying letter) or when contacted upon completion of the repair. Please submit all raised information on your charge card when paying by this means.

5.) Transportation Charges: Units should be returned, transportation and insurance charges prepaid. Return transportation and insurance charges will be billed to you with other costs.

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2.) Connect station ground buss to terminal on tuner marked GND with heavy metalic braid or wire. This lead should go directly to the earth ground system with as short a lead as possible.

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ANTENNA SYSTEMS MATCHING THEORY

Most transmitters are designed to work into a 50-75 ohm resistive load, and they are not able to effectively supply rf power to loads that depart far from these values. However, many antenna systems, which include the antenna and the transmission line, have complex impedances that make it difficult if not impossible to load the transmitter properly. These impedances are a function of the operating frequency, type of antenna, type and length of transmission line, height of antenna and its proximity to other objects.

Models 247/277 provide a coupling method to convert the resistive/reactive load to a pure resistance of 50 ohms that will accept maximum power from the transmitter. This is not to say that any and all antennas, when converted to a 50 ohm resistive impedance by means of a tuner, will give identical performance. To best understand the tuner adjustments required, it is necessary to have a fundamental knowledge of how antenna systems function. To this end, a short technical discussion follows. It is recommended that additional reading on the subject be made by those interested in obtaining maximum performance from their antenna systems. The ARRL Antenna Handbook, ARRL Amateur's Radio Handbook (antenna and transmission line sections) and other antenna books published by the publishers of Amateur Radio magazines are excellent sources of information. For those already versed in antenna theory, skip down to the OPERATION section.

THE ANTENNA - Any conductor that has rf currents flowing in it can be looked on as an antenna or radiator. The extent to which power leaves the conductor and radiates into the surrounding medium depends on many factors -- length, frequency, amount of current, configuration, etc. Since the antenna absorbs power from the device feeding it, it can be replaced with a resistance whose value is such that the power delivered to this resistance is the same as that delivered to the antenna. The value of this resistance is now a measure of the radiating effectiveness of the antenna and is termed "radiation resistance". For a given value of antenna current, the higher this resistance, the more power that is radiated. ($P=I^2R$)

Due to the facts that an antenna has physical length, that currents travel at a velocity less than instantaneous and that the conductor posseses a certain amount of self inductance and capacitance, the current at the feed point may not be in phase with the voltage at this point. As a result, the impedance at this point may not look like the pure resistance first suspected, but as an impedance consisting of resistance and either inductive or capacitive reactance. This added reactance will limit the amount of current supplied to the antenna for a given voltage, and therefore reduce the amount of radiated power. The reactance does not absorb power in itself -- only a resistance can do that -- but its presence reduces the overall radiated power and antenna current.

There are two ways to restore the power to its non-reactive value. The first, which is not the preferred way because it does not maximize power transfer, is to raise the feed point voltage enough so that the current returns to its original value. The second, and preferred method, is to add a reactance in series, equal in value but opposite in type (sign) to the reactance value of the antenna. For example, if the antenna at the operating frequency presents an inductive reactance of 100 ohms (+j100) along with a resistance of 50 ohms, inserting a capacitor whose reactance is also 100 ohms (-j100) in series has the effect of cancelling out the reactance of the antenna, leaving only the 50 ohms resistive. This can be looked on as a series R,L,C circuit that is in resonance, whose total impedance is only that of the resistance. Another term for this approach to maximize power transfer is "conjugate impedance matching".

In the above example, we used a value of 50 ohms for the radiation resistance. If this value were not 50 but 150 ohms, the impedance after cancelling the reactance out would be 150 ohms. Connecting this load to the transmitterdesigned to operate with 50 ohms load would not result in optimum power transfer. It would, however, be better than leaving the inductive reactance in, since the antenna current is maximized for the conditions that do exist. To obtain design performance, it is necessary to transform the 150 ohms to 50. This can be done with a transformer with a turns ratio of 1.73 to 1. (Impedance transformation is equal to the square of the turns ratio.) It is also possible to accomplish this transformation with a parallel tuned circuit with primary and secondary taps properly located on the inductor, or using two or more capacitors in series with taps taken from the series string. Under these conditions, the transceiver will deliver rated power to the antenna.

One last observation before we go on. The antenna impedance in the above example was stated as that at the feed point. If we now feed the antenna at a different location along the conductor, the impedance will be different, both resistive and reactive components. There are an infinite number of impedance choices available, depending on where the tap is made. This factor is helpful in designing and matching antennas. The factors that determine this impedance are the current and voltage values at this point, and the phase between them.

THE TRANSMISSION LINE - In the above example, we assumed that the transmitter output was connected directly to the feed point. This is hardly practical. So that the transmitter can be located at a distance from the antenna, we use a transmission line to deliver the power. Unless we have a perfectly matched system, i.e. antenna, line and transmitter output impedances all the same value without reactive components, the addition of the transmission line completely changes the picture. The transmitter will not see the antenna impedance of 50 ohms resistive and 100 ohms inductive reactance, but some other combination. It will depend on the electrical length of the line, its characteristic impedance and frequency. The impedance at the transmitter end is what we are interested in, and the inductive component may even be changed to capacitance. (Only when the electrical length of the line is an exact multiple of the half wavelength will the impedance at the transmitter be the same as the antenna impedance.)

Briefly, the line characteristic impedance is determined by the physical dimensions of the line -- wire diameter and spacing -- and the dielectric of the material in between. The wire also posseses a resistive component which will dissipate power when current flows through it to the antenna. This shows up as heat loss and dictates use of low loss cable. Formulas for coax and open wire line impedances are given in the handbooks.

Since rf currents flow in the transmission line, one may ask if it then becomes an antenna. In the case of coax type lines, the current should flow on the inside surface of the outer conductor and outer surface of the inner conductor. The electric and magnetic fields caused by the current flow are confined between the two, so none can escape and be radiated. If a system configuration results in some rf current flowing on the outer surface of the outer conductor, such as when a dipole is fed with coax without a balun or other means of changing the feed line from an unbalanced to balanced configuration, it will radiate power. In the case of parallel lines, the current in one conductor at a given location should be flowing in the opposite direction to the current in the adjacent conductor, and if the system is well balanced, the amplitudes of the two will be equal. Under these conditions, the two sets of fields exactly cancel each other and very little radiation will result. If the two currents are not equal or not in exact opposite phase, there will be radiation. Also, if the spacing between lines is a considerable portion of the wavelength, radiation will occur. This is not a factor below VHF.

One final characteristic of transmission lines should be mentioned. The rf current flowing in the line travels at a speed less than that of radiated power in a vacuum, or the speed of light, both 186,000 miles per second. This slowing is caused by the dielectric property of the medium through which the field traverses. In coax cables it is polyethelene between inner and outer conductors, and in parallel lines, it may be the plastic between the conductors in the case of twin-lead type line, or the air and plastic spacers in open wire

types. The ratio of the speed in the line to the speed in a vacuum (air is almost the same) is called the velocity factor of the cable. It is always less than unity. Because of this slowing, the physical length of a transmission line is not the same as the electrical length. For example, the wavelength in free space of a 30 MHz signal is exactly 10 meters. A transmission line 10 meters long will be one full wavelength only if the dielectric between the conductors is air. In the case of coax cable with polyethelene dielectric, the velocity factor runs about 0.67. The same 10 meter length of cable will now appear electrically as an open wire or air dielectric cable 15 meters long (10 divided by 0.67). This is equivalent to one and one half wavelengths. A polyethelene type cable would only have to be 6.7 meters long to be one wavelength.

EFFECT OF TRANSMISSION LINE ON ANTENNA IMPEDANCE - As a result of all of the above, in situations where we do not have a matched system throughout, and this is most of the time, the impedance presented to the transmission line by the antenna sets up standing waves on the line. These standing waves will alter the antenna impedance all along the line toward the transmitter. What we really want to accomplish with the antenna tuner is to take whatever impedance that is established at the transmitter end of the line and alter it to a 50 ohm resistance. Then the transmitter will be happy, at least. The tuner will not affect the mismatch of antenna to line -- only constructing the antenna differently will do that --nor eliminate a standing wave on the transmission line. It will eliminate a standing wave on the line between transmitter and tuner input, but not on the output side of the tuner. A good antenna is still needed to "get out". If the antenna has a low resistance, the tuner will transform it, along with the cable loss resistance, to 50 ohms. The full power will enter the system, but it will be divided between radiation and cable heat loss. It is not uncommon that more than half of the available power is wasted in cable losses, even with low loss cable. It just gets a bit hotter. The split depends entirely on the ratio of radiation resistance to loss resistance.

What is the impedance established at the transmitter end of the line? It depends first on the antenna impedance, which is then transformed by the line. This transformation is dependent on frequency, electrical length of the line and the loss in the line. In an Amateur setup where many different frequencies are used with the same antenna, there will be a multitude of impedances presented to the tuner, so adjustment of the matching network will be required as frequency is changed.

STANDING WAVE RATIO - A measure of how badly a system is mismatched is given by the standing wave ratio (SWR) on the line. SWR is the ratio of the maximum voltage encountered along a transmission line greater than one half wavelength long to the minimum voltage. It is also the ratio of maximum to minimum current. The more nearly uniform the voltage distribution along the line, the closer matched it is, and the ultimate is when the voltage is constant down the length of a lossless line, or drops slowly and uniformly along a line with losses. This is the matched condition, represented by a 1 to 1 SWR. The impedance at the load end of such a line is the same as that at the generator end. When adjusting a matching network properly, the way to do it is to observe the SWR and tune for as low a ratio as possible.

The SWR is also an indication of the value of resistance at the load end. The ratio is the same as the ratio of load resistance to line characteristic impedance. This ratio can mean that the load is either greater than or less than the line's impedance. For example, if the SWR on a length of 50 ohm line is 3 to 1, the load resistance is either 150 ohms or 16.7 ohms (3 times 50 or one third of 50). This is only accurate with pure resistive loads.

It can be shown mathematically that a 2 to 1 SWR in a system which has the transmitter output impedance equal to the line impedance delivers 89% of the power to the load that it would if perfectly matched. This relates to a power loss of half a decibel -- hardly noticeable in signal strength. At a 3 to 1 ratio, the loss becomes appreciable with 25% of the power lost. So in adjusting antenna tuners, it is a nice feeling if you achieve a 1 to 1 match, but in reality, anything below 2 to 1 is satisfactory. Line losses do increase a bit also with increasing SWR, but it is still a small fraction of a dB at 2:1.

TRANSMATCH TUNER CIRCUIT - A look at the schematic reveals that the circuit used in TEN-TEC tuners consists of a parallel circuit of inductor L1 and two variable capacitors connected in series. The input is applied to the center of the series capacitors and ground. Another variable capacitor is connected in series with the output lead to the COAX and SINGLE WIRE terminals. For ballanced outputs, balun L2 is connected so that the basic tuner output is applied to one half of the winding, and transformer action produces the opposite half with reference to chassis ground. Hence the balanced output will provide twice the rf voltage, symetrical to ground. The impedance transformation with this arrangement is a step-up of four times on the antenna side. This circuit should match just about any antenna system impedance to 50 ohms.

When the circuit is tuned for a match, the parallel tuned circuit will be approximately in resonance at the frequency involved. Reactive components in the load will be compensated for by both the series output capacitor and a slight off-resonance setting of the parallel circuit. It will be noted that since both inductor and shunt capacitor are variable, there are many possible settings of these components that will resonate at a given frequency. A high inductance with small capacitance will resonate just as well as a small inductance with large capacitor. Is one way better than the other? The answer is yes. When matching to high impedances, there must be a certain amount of inductance present before a match is achievable. The step up transformation of resistance is dependent on the "Q" of the circuit, which is a function of the inductance. In addition, the frequency range over which operation with acceptable SWR is possible without retuning is dependent on the L to C ratio of the circuit. The smaller this ratio, the greater the bandwidth. (To illustrate how effective this becomes at low frequencies, the following results from lab tests at 3.75 MHz and a 50 ohm load were obtained: With maximum L/C ratio, i.e. INDUCTANCE setting of 47 and SHUNT CAP. about 3.2, the frequency range before a SWR of 2 to 1 was encountered.was 50 kHz, $\pm$ 25 kHz on either side of the center frequency. Using the lowest L/C ratio, INDUCTANCE set to 14 and SHUNT CAP. to 10, range increased to over 400 kHz, almost the entire 80 meter band.) With the broader band L/C ratio, tuner adjustments become less critical and the SWR meter dip to 1 to 1 is broad. With high L/C ratios, the dip is very narrow and sharp, and it may be easily overlooked.

To summarize the above: Best and broadest operation is obtained when SHUNT CAP. is set to maximum possible setting that will allow a match to 1 to 1. Under these conditions, INDUCTANCE will be minimum at which resonance can be attained. SERIES CAP. is primarily used when reactive components need cancelling out. With single wire resistive antenna, SERIES CAP. setting will be near maximum.

OVERALL SUMMARY

1.) Any antenna can be represented as an equivalent resistive/reactive impedance whose resistive component, termed radiation resistance, is a measure of the power radiated. Reactance can be either inductive or capacitive.

2.) Antenna impedance is a function of frequency, configuration, selection of feed point location, height above ground and nearness to surrounding objects.

3.) The reactive portion of the impedance does not absorb power but limits the amount of power radiated by the resistive component. It is best to eliminate the reactive component, by inserting an equal value reactance in series, but of the opposite type.

4.) Best system performance is attained when antenna impedance is purely resistive with value equal to transmission line impedance, which in turn equals transmitter output impedance.

5.) Since antennas seldom present matched impedances to line over a band of frequencies and from band to band, a partial solution to using these mismatched systems is to convert the impedances at the transmitter end of the line to what the transmitter is designed for, with an antenna tuner.

6.) The transmission line will change the antenna impedance in both resistive and reactive values at the transmitter end, depending on the line's

electrical length, frequency and characteristic impedance.

7.) Due to slowing down of the current flow in the transmission line from that in free space, the electrical length of a line will be longer than the physical length.

8.) One special situation where the line does not alter the impedance is when its length is an exact multiple of the electrical have wavelength.

9.) An antenna tuner will not affect the antenna impedance nor the standing wave condition on the transmission line. It will correct the SWR on that portion of the line between transmitter output and tuner input, so that the transmitter will supply rated power to the system.

10.) Standing wave ratio, SWR, is a measure of the mis-match of the system and is used as the indicator when making tuner adjustments. SWR is direct ratio ofload resistance to line's characteristic impedance.

11.) SWR other than 1 to 1 indicates two possible impedances, one greater and one less than characteristic impedance.

12.) Any SWR value less than 2 to 1 is considered a good match.

13.) Transmatch tuner circuit can provide a number of different control settings, all of which produce a match. Difference is in L to C ratio of the tuned circuit.

14.) The lowest L/C ratio will provide greatest bandwidth for a given SWR limit. If adjusted for maximum bandwidth, retuning across the band will only be necessary on 160 and 80 meters, and possibly on extremes of 40 meter band.

OPERATION

1.) Always make tuner adjustments with minimum required power from transmitter. To do this, set sensitivity of SWR bridge to maximum, fully CW on Model 277.

2.) Set up meter to read SWR. This is REV. switch position on Model 277.

3.) Set both SERIES CAP. and SHUNT CAP. fully clockwise, (10 position).

4.) Apply just enough drive to transmitter so that meter reading is approximately half scale.

5.) Attempt to find a null as INDUCTANCE control is increased from full CCW position. Null may not be deep at this point. If null is not apparent, reduce setting of SERIES CAP. a bit and try again.

6.) With INDUCTANCE set for best null, try to deepen null with SERIES CAP. If rotating this control CCW from 10 position causes meter deflection to increase, set INDUCTANCE control one step clockwise and try dipping with SHUNT CAP. again. Continue until SHUNT CAP. can provide a null near its full maximum position. Adjust transmitter drive to provide adequate meter deflection.

7.) If null produced is not 1 to 1 with rated drive, decrease setting of SERIES CAP. a bit and renull with SHUNT CAP. Continue this procedure until 1 to 1 reading is obtained with full drive, or best null below 2 to 1 is attained. (If by decreasing SERIES CAP. resonance is not attainable with SHUNT CAP., increase INDUCTANCE one more notch and retune capacitors.

8.) To accurately determine if SWR is sufficientle low, set FWD. meter deflection to indexed mark on meter with SENSITIVITY control and read SWR in REV. switch position. Reading below 2 is acceptable.

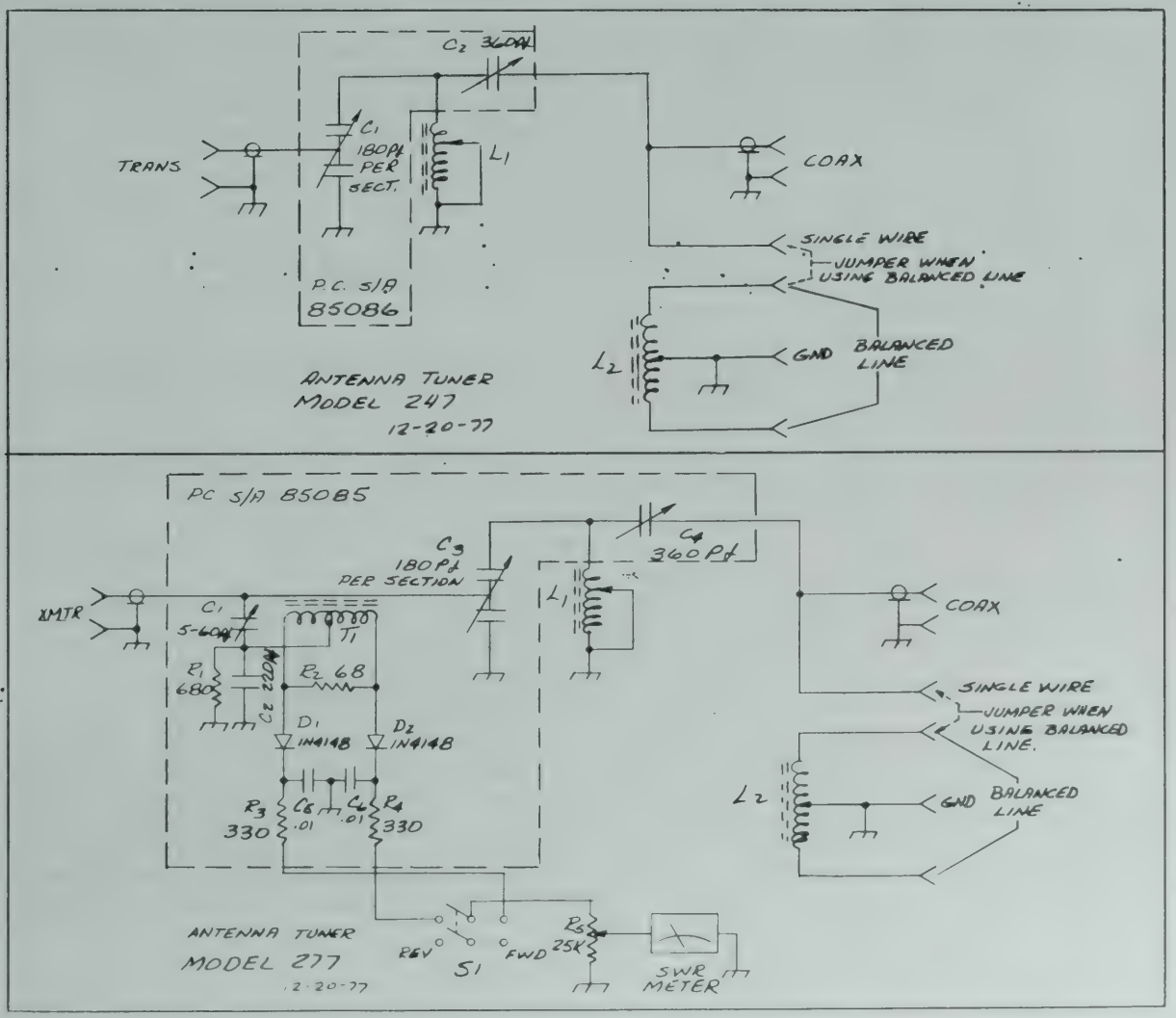
9.) It is good procedure to leave SWR meter in REV. position so that you can monitor match while operating. If you tune too far from resonance, it will be apparent and retuning can be initiated.

10.) It is convenient to record control settings for each band of operation and possibly at 3.6 and 3.9 MHz of 80 meter band. Then tune-up will be simplified when changing bands because starting points will already be established.

Approximate starting points for control settings for each band are given in Table I below. These guideline settings require some alteration for your specific antenna systems, and exact settings should be determined using the procedures outlined above. Reactive loads will alter the values somewhat, but mainly in the SERIES CAP. columns.

TABLE I
GUIDELINE CONTROL SETTINGS

FREQ. MHz	UNBALANCED COAXIAL FEED SYSTEMS									SINGLE WIRE			BALANCED LINE		
	50 OHMS			150 OHMS			17 OHMS			800 OHMS			300 OHMS		
	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.
1.8	7	10	38	7	10	44	10	10	29	-	-	-	8	10	34
3.6	7	10	15	7	10	17	9	10	11	10	10	23	6	10	16
3.9	7	10	13	7	10	15	9	10	10	10	10	21	6	10	14
7.1	6	10	6	7	9	7	7	10	5	10	7	12	5	10	7
14.2	4	9	3	6	7	3	4	10	2	10	5	6	4	10	3
21.2	2	8	2	5	9	1	1	7	2	10	3	4	3	7	2
28.5	1	7	1	2	5	1	.0	9	1	10	2	3	3	7	1



TEN-TEC, INC.
Sevierville, TN 37862

REPAIR DEPARTMENT TELEPHONE
615-428-0364

LIMITED WARRANTY AND SERVICE POLICY

TEN-TEC, INC. warrants all products to be free from defects in material and workmanship for a period of one year after date of purchase, under these conditions:

1.) Registration: The warranty card must be returned promptly to establish the warranty period. Our card file also serves as a check on stolen equipment which may be sent in for repair. Please notify us immediately if your TEN-TEC equpment is stolen.

2.) Original Purchaser: This warranty applies only to the original purchaser. Your returned warranty card listing from whom purchased establishes you as the original purchaser.

3.) Communication with the Factory: If trouble develops, contact your TEN-TEC dealer from whom you purchased the unit. He is obligated to try to correct the malfunction or return the unit to us. If he is unable to correct the fault, you or the dealer should contact the factory by mail or by telephone 615-428-0364, giving serial number if assigned, symptoms of fault and conditions under which they appear. You will be advised whether to return the unit to us or to try a replacement plug-in assembly that will be sent to you. To facilitate service calls, please use our direct Repair Department telephone number, 615-428-0364. (NO COLLECT CALLS, PLEASE.)

4.) In-Warranty Field Repairs: To expedite repairs TEN-TEC will send replacement assemblies prior to receiving the suspected defective one from you. The replacement will be billed on a 30 day memo, and credit will be issued when the defective unit is returned to us. No remittance or deposit is required. If the defective assembly is not returned within 30 days, you will be billed.

5.) Return to Non-Selling Dealer: If you return the in-warranty unit to an authorized TEN-TEC dealer who did not sell the unit to you, he may, at his option, repair the unit or handle the return to the factory. Under these conditions TEN-TEC will repair or replace all defective components without charge, but reasonable labor charges may be levied by the servicing dealer. TEN-TEC is not liable for labor charges under these conditions.

6.) Proper Delivery: If the unit is returned to the factory, it must be adequately packed. A note should be included outlining the problem, conditions under which it appears, and attempted remedies. The more specific you are, the better the possibility of a complete fix. Shipping charges to the factory are to be borne by you. Unit will be returned, transportation paid by TEN-TEC.

7.) Extended Pro-Rata Warranty on Models 540/544/545/546 Output Transistors: The output transistors on these models are unconditionally guaranteed against damage for a period of one year after date of purchase, under any load condition or mode of operation, except for static discharge on the antenna or direct lightning strike. If they fail after the warranty period, the following replacement schedule will apply, provided that our service department makes the repair. (Prices listed are maximum and subject to reduction, depending on current transistor prices at time of repair.)

1 to 2 years	2 to 3 years	3 to 5 years
$12.00 each	$15.00 each	$18.00 each

(Two transistors per transceiver. Labor not included.)

8.) Exclusions: This warranty does not apply to damage caused by mishandling, lightning, voltages in excess of rating, reverse polarity of DC supply, or changes in circuits. Claims for damage in transit should be filed with the carrier. This warranty, however, is NOT voided for attempted repairs of defective units, or for incorporation of additional components such as switches, etc. when there is no change in the basic circuit. Under no circumstances is TEN-TEC liable for consequential damage to person or property by use of this unit.

9.) TEN-TEC reserves the right to make any improvements to its products which it may deem desirable without obligating itself to install such improvements in its previously manufactured products.

10.) This warranty is given in lieu of any other warranty expressed or implied.

Out-of-Warranty Repairs

1.) Field Repairs: New circuit boards or discrete components can often be supplied to eliminate the cost and bother of shipping the complete unit to us. A nominal charge will be made for the material sent. Certain assemblies intregal with the main chassis, such as VFO assemblies and rack tuning mechanisms, are not field replaceable.

2.) Returned Units: Along with the unit, please submit a complete report on the nature of the malfunction and the conditions under which it occurs. This will enable our service department to pay special attention to your problem area and reduce overall labor costs. No matter what the malfunction is, every unit will be given a complete alignment and operational check before being returned.

3.) Quotations: Quotations on repair work will be given on request, after examination of the unit. The amount quoted will be firm for the specific work outlined in the quotation. Should additional material or labor requirements come to light after the repair is initiated, you will be contacted for approval before this phase of the repair is started.

4.) Repair Charge Payment: Charges below the $25.00 level will be billed to you after completion of the work and at the time of re-shipment. A report of all work done and parts used will accompany the bill. For charges greater than $25.00, prepayment will be required before the unit is returned. One of three methods of payment may be selected. 1.) Upon completion of the work the billing will be made but the unit will be held here. Upon receipt of the payment, the unit will be shipped. 2.) The unit will be returned to you on a COD basis, with COD charges borne by you. 3.) The repair charges may be paid by either MasterCharge or BankAmericard/VISA.

Approval for COD or charge card options can be given either at the time the unit is submitted to us (in the accompanying letter) or when contacted upon completion of the repair. Please submit all raised information on your charge card when paying by this means.

5.) Transportation Charges: Units should be returned, transportation and insurance charges prepaid. Return transportation and insurance charges will be billed to you with other costs.

TEN-TEC MODELS 247 & 277 ANTENNA TUNERS

GENERAL

Models 247 and 277 Antenna Tuners are inductive/capacitive networks used for matching unbalanced 50-75 ohm output impedances of transmitters and transceivers to a variety of loads, both balanced and unbalanced. They operate over a frequency range of 1.8 to 30 MHz. Both incorporate the universal Transmatch circuit. Model 277 has, in addition to the tuner components, a built-in SWR bridge and meter.

SPECIFICATIONS

Circuit: Universal Transmatch.
Rf Power: 100 watts, continuous; 200 watts, intermittent.
Capacitor Voltage Rating: 1 kV.
Toroid: 47 tap, 18 guage silver plated wire on 2" diameter core.
Input Impedance: 50-75 ohms.
Output: Matches all loads, balanced and unbalanced. Maximum balanced load 1.8 to 4.0 MHz is 600 ohms.
Frequency Range: 1.8 to 30 MHz.

Model 247 Only:

Finish: Etched aluminum chassis and front panel; black textured sides and top.
Size: HWD 2-15/16" x 7-3/4" x 6-11/16".
Weight: 3 lbs.

Model 277 Only:

Meter: SWR bridge with forward/reverse switch.
Finish: Grey chassis and front panel; black textured sides and top.
Size: HWD 3-1/2" x 10-1/4" x 6-1/2".
Weight: 3 lbs.

INSTALLATION

1.) Connect coaxial output of transmitter to coaxial input of tuner with short length of RG-8 or RG-58 cable. Connectors are PL-259 types. Notice: To reduce possibility of rf from getting into transmitter, position tuner as far away from transmitter as is practical. Never set tuner directly on top of transmitter.

2.) Connect station ground buss to terminal on tuner marked GND with heavy metalic braid or wire. This lead should go directly to the earth ground system with as short a lead as possible.

3.) Connect transmission line to appropiate terminals on tuner as follows:

A.) For unbalanced transmission lines, use connector labeled COAX and coaxial type cable. Do not connect jumper between SINGLE WIRE and one BALANCED LINE terminal.

B.) For single wire feeds, connect line to SINGLE WIRE terminal.

C.) For balanced line feed systems, first jumper terminals indicated, SINGLE WIRE and one BALANCED LINE, with short wire. Connect feed line to two BALANCED LINE terminals.

In both single wire and balanced line systems, take special care to route transmission line as far away from station equipment as possible. Never drape lines over transmitter. These lines may have a high voltage point inside the shack which presents high rf fields.

4.) If your tuner is Model 247 and no bridge is incorporated in the transmitter, insert a SWR bridge in series with the lead between transmitter output and tuner input. Do not place bridge in output line of tuner. SWR bridge is necessary for proper tuner adjustment. (When using Model 240 One Sixty Converter with TEN-TEC Models 540/544 tranceiver, SWR bridge in transceiver cannot be used on 160 meter band for tuner adjustment. Either Model 277 with SWR bridge incorporated or a separate bridge inserted in line between Model 240 output and antenna tuner input must be used.)

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Due to the facts that an antenna has physical length, that currents travel at a velocity less than instantaneous and that the conductor posseses a certain amount of self inductance and capacitance, the current at the feed point may not be in phase with the voltage at this point. As a result, the impedance at this point may not look like the pure resistance first suspected, but as an impedance consisting of resistance and either inductive or capacitive reactance. This added reactance will limit the amount of current supplied to the antenna for a given voltage, and therefore reduce the amount of radiated power. The reactance does not absorb power in itself -- only a resistance can do that -- but its presence reduces the overall radiated power and antenna current.

There are two ways to restore the power to its non-reactive value. The first, which is not the preferred way because it does not maximize power transfer, is to raise the feed point voltage enough so that the current returns to its original value. The second, and preferred method, is to add a reactance in series, equal in value but opposite in type (sign) to the reactance value of the antenna. For example, if the antenna at the operating frequency presents an inductive reactance of 100 ohms (+j100) along with a resistance of 50 ohms, inserting a capacitor whose reactance is also 100 ohms (-j100) in series has the effect of cancelling out the reactance of the antenna, leaving only the 50 ohms resistive. This can be looked on as a series R,L,C circuit that is in resonance, whose total impedance is only that of the resistance. Another term for this approach to maximize power transfer is "conjugate impedance matching".

In the above example, we used a value of 50 ohms for the radiation resistance. If this value were not 50 but 150 ohms, the impedance after cancelling the reactance out would be 150 ohms. Connecting this load to the transmitterdesigned to operate with 50 ohms load would not result in optimum power transfer. It would, however, be better than leaving the inductive reactance in, since the antenna current is maximized for the conditions that do exist. To obtain design performance, it is necessary to transform the 150 ohms to 50. This can be done with a transformer with a turns ratio of 1.73 to 1. (Impedance transformation is equal to the square of the turns ratio.) It is also possible to accomplish this transformation with a parallel tuned circuit with primary and secondary taps properly located on the inductor, or using two or more capacitors in series with taps taken from the series string. Under these conditions, the transceiver will deliver rated power to the antenna.

One last observation before we go on. The antenna impedance in the above example was stated as that at the feed point. If we now feed the antenna at a different location along the conductor, the impedance will be different, both resistive and reactive components. There are an infinite number of impedance choices available, depending on where the tap is made. This factor is helpful in designing and matching antennas. The factors that determine this impedance are the current and voltage values at this point, and the phase between them.

THE TRANSMISSION LINE - In the above example, we assumed that the transmitter output was connected directly to the feed point. This is hardly practical. So that the transmitter can be located at a distance from the antenna, we use a transmission line to deliver the power. Unless we have a perfectly matched system, i.e. antenna, line and transmitter output impedances all the same value without reactive components, the addition of the transmission line completely changes the picture. The transmitter will not see the antenna impedance of 50 ohms resistive and 100 ohms inductive reactance, but some other combination. It will depend on the electrical length of the line, its characteristic impedance and frequency. The impedance at the transmitter end is what we are interested in, and the inductive component may even be changed to capacitance. (Only when the electrical length of the line is an exact multiple of the half wavelength will the impedance at the transmitter be the same as the antenna impedance.)

Briefly, the line characteristic impedance is determined by the physical dimensions of the line -- wire diameter and spacing -- and the dielectric of the material in between. The wire also posseses a resistive component which will dissipate power when current flows through it to the antenna. This shows up as heat loss and dictates use of low loss cable. Formulas for coax and open wire line impedances are given in the handbooks.

Since rf currents flow in the transmission line, one may ask if it then becomes an antenna. In the case of coax type lines, the current should flow on the inside surface of the outer conductor and outer surface of the inner conductor. The electric and magnetic fields caused by the current flow are confined between the two, so none can escape and be radiated. If a system configuration results in some rf current flowing on the outer surface of the outer conductor, such as when a dipole is fed with coax without a balun or other means of changing the feed line from an unbalanced to balanced configuration, it will radiate power. In the case of parallel lines, the current in one conductor at a given location should be flowing in the opposite direction to the current in the adjacent conductor, and if the system is well balanced, the amplitudes of the two will be equal. Under these conditions, the two sets of fields exactly cancel each other and very little radiation will result. If the two currents are not equal or not in exact opposite phase, there will be radiation. Also, if the spacing between lines is a considerable portion of the wavelength, radiation will occur. This is not a factor below VHF.

One final characteristic of transmission lines should be mentioned. The rf current flowing in the line travels at a speed less than that of radiated power in a vacuum, or the speed of light, both 186,000 miles per second. This slowing is caused by the dielectric property of the medium through which the field traverses. In coax cables it is polyethelene between inner and outer conductors, and in parallel lines, it may be the plastic between the conductors in the case of twin-lead type line, or the air and plastic spacers in open wire

types. The ratio of the speed in the line to the speed in a vacuum (air is almost the same) is called the velocity factor of the cable. It is always less than unity. Because of this slowing, the physical length of a transmission line is not the same as the electrical length. For example, the wavelength in free space of a 30 MHz signal is exactly 10 meters. A transmission line 10 meters long will be one full wavelength only if the dielectric between the conductors is air. In the case of coax cable with polyethelene dielectric, the velocity factor runs about 0.67. The same 10 meter length of cable will now appear electrically as an open wire or air dielectric cable 15 meters long (10 divided by 0.67). This is equivalent to one and one half wavelengths. A polyethelene type cable would only have to be 6.7 meters long to be one wavelength.

EFFECT OF TRANSMISSION LINE ON ANTENNA IMPEDANCE - As a result of all of the above, in situations where we do not have a matched system throughout, and this is most of the time, the impedance presented to the transmission line by the antenna sets up standing waves on the line. These standing waves will alter the antenna impedance all along the line toward the transmitter. What we really want to accomplish with the antenna tuner is to take whatever impedance that is established at the transmitter end of the line and alter it to a 50 ohm resistance. Then the transmitter will be happy, at least. The tuner will not affect the mismatch of antenna to line -- only constructing the antenna differently will do that --nor eliminate a standing wave on the transmission line. It will eliminate a standing wave on the line between transmitter and tuner input, but not on the output side of the tuner. A good antenna is still needed to "get out". If the antenna has a low resistance, the tuner will transform it, along with the cable loss resistance, to 50 ohms. The full power will enter the system, but it will be divided between radiation and cable heat loss. It is not uncommon that more than half of the available power is wasted in cable losses, even with low loss cable. It just gets a bit hotter. The split depends entirely on the ratio of radiation resistance to loss resistance.

What is the impedance established at the transmitter end of the line? It depends first on the antenna impedance, which is then transformed by the line. This transformation is dependent on frequency, electrical length of the line and the loss in the line. In an Amateur setup where many different frequencies are used with the same antenna, there will be a multitude of impedances presented to the tuner, so adjustment of the matching network will be required as frequency is changed.

STANDING WAVE RATIO - A measure of how badly a system is mismatched is given by the standing wave ratio (SWR) on the line. SWR is the ratio of the maximum voltage encountered along a transmission line greater than one half wavelength long to the minimum voltage. It is also the ratio of maximum to minimum current. The more nearly uniform the voltage distribution along the line, the closer matched it is, and the ultimate is when the voltage is constant down the length of a lossless line, or drops slowly and uniformly along a line with losses. This is the matched condition, represented by a 1 to 1 SWR. The impedance at the load end of such a line is the same as that at the generator end. When adjusting a matching network properly, the way to do it is to observe the SWR and tune for as low a ratio as possible.

The SWR is also an indication of the value of resistance at the load end. The ratio is the same as the ratio of load resistance to line characteristic impedance. This ratio can mean that the load is either greater than or less than the line's impedance. For example, if the SWR on a length of 50 ohm line is 3 to 1, the load resistance is either 150 ohms or 16.7 ohms (3 times 50 or one third of 50). This is only accurate with pure resistive loads.

It can be shown mathematically that a 2 to 1 SWR in a system which has the transmitter output impedance equal to the line impedance delivers 89% of the power to the load that it would if perfectly matched. This relates to a power loss of half a decibel -- hardly noticeable in signal strength. At a 3 to 1 ratio, the loss becomes appreciable with 25% of the power lost. So in adjusting antenna tuners, it is a nice feeling if you achieve a 1 to 1 match, but in reality, anything below 2 to 1 is satisfactory. Line losses do increase a bit also with increasing SWR, but it is still a small fraction of a dB at 2:1.

TRANSMATCH TUNER CIRCUIT - A look at the schematic reveals that the circuit used in TEN-TEC tuners consists of a parallel circuit of inductor L1 and two variable capacitors connected in series. The input is applied to the center of the series capacitors and ground. Another variable capacitor is connected in series with the output lead to the COAX and SINGLE WIRE terminals. For ballanced outputs, balun L2 is connected so that the basic tuner output is applied to one half of the winding, and transformer action produces the opposite half with reference to chassis ground. Hence the balanced output will provide twice the rf voltage, symetrical to ground. The impedance transformation with this arrangement is a step-up of four times on the antenna side. This circuit should match just about any antenna system impedance to 50 ohms.

When the circuit is tuned for a match, the parallel tuned circuit will be approximately in resonance at the frequency involved. Reactive components in the load will be compensated for by both the series output capacitor and a slight off-resonance setting of the parallel circuit. It will be noted that since both inductor and shunt capacitor are variable, there are many possible settings of these components that will resonate at a given frequency. A high inductance with small capacitance will resonate just as well as a small inductance with large capacitor. Is one way better than the other? The answer is yes. When matching to high impedances, there must be a certain amount of inductance present before a match is achievable. The step up transformation of resistance is dependent on the "Q" of the circuit, which is a function of the inductance. In addition, the frequency range over which operation with acceptable SWR is possible without retuning is dependent on the L to C ratio of the circuit. The smaller this ratio, the greater the bandwidth. (To illustrate how effective this becomes at low frequencies, the following results from lab tests at 3.75 MHz and a 50 ohm load were obtained: With maximum L/C ratio, i.e. INDUCTANCE setting of 47 and SHUNT CAP. about 3.2, the frequency range before a SWR of 2 to 1 was encountered was 50 kHz, $\pm$ 25 kHz on either side of the center frequency. Using the lowest L/C ratio, INDUCTANCE set to 14 and SHUNT CAP. to 10, range increased to over 400 kHz, almost the entire 80 meter band.) With the broader band L/C ratio, tuner adjustments become less critical and the SWR meter dip to 1 to 1 is broad. With high L/C ratios, the dip is very narrow and sharp, and it may be easily overlooked.

To summarize the above: Best and broadest operation is obtained when SHUNT CAP. is set to maximum possible setting that will allow a match to 1 to 1. Under these conditions, INDUCTANCE will be minimum at which resonance can be attained. SERIES CAP. is primarily used when reactive components need cancelling out. With single wire resistive antenna, SERIES CAP. setting will be near maximum.

OVERALL SUMMARY

1.) Any antenna can be represented as an equivalent resistive/reactive impedance whose resistive component, termed radiation resistance, is a measure of the power radiated. Reactance can be either inductive or capacitive.

2.) Antenna impedance is a function of frequency, configuration, selection of feed point location, height above ground and nearness to surrounding objects.

3.) The reactive portion of the impedance does not absorb power but limits the amount of power radiated by the resistive component. It is best to eliminate the reactive component, by inserting an equal value reactance in series, but of the opposite type.

4.) Best system performance is attained when antenna impedance is purely resistive with value equal to transmission line impedance, which in turn equals transmitter output impedance.

5.) Since antennas seldom present matched impedances to line over a band of frequencies and from band to band, a partial solution to using these mismatched systems is to convert the impedances at the transmitter end of the line to what the transmitter is designed for, with an antenna tuner.

6.) The transmission line will change the antenna impedance in both resistive and reactive values at the transmitter end, depending on the line's

electrical length, frequency and characteristic impedance.

7.) Due to slowing down of the current flow in the transmission line from that in free space, the electrical length of a line will be longer than the physical length.

8.) One special situation where the line does not alter the impedance is when its length is an exact multiple of the electrical have wavelength.

9.) An antenna tuner will not affect the antenna impedance nor the standing wave condition on the transmission line. It will correct the SWR on that portion of the line between transmitter output and tuner input, so that the transmitter will supply rated power to the system.

10.) Standing wave ratio, SWR, is a measure of the mis-match of the system and is used as the indicator when making tuner adjustments. SWR is direct ratio ofload resistance to line's characteristic impedance.

11.) SWR other than 1 to 1 indicates two possible impedances, one greater and one less than characteristic impedance.

12.) Any SWR value less than 2 to 1 is considered a good match.

13.) Transmatch tuner circuit can provide a number of different control settings, all of which produce a match. Difference is in L to C ratio of the tuned circuit.

14.) The lowest L/C ratio will provide greatest bandwidth for a given SWR limit. If adjusted for maximum bandwidth, retuning across the band will only be necessary on 160 and 80 meters, and possibly on extremes of 40 meter band.

OPERATION

1.) Always make tuner adjustments with minimum required power from transmitter. To do this, set sensitivity of SWR bridge to maximum, fully CW on Model 277.

2.) Set up meter to read SWR. This is REV. switch position on Model 277.

3.) Set both SERIES CAP. and SHUNT CAP. fully clockwise, (10 position).

4.) Apply just enough drive to transmitter so that meter reading is approximately half scale.

5.) Attempt to find a null as INDUCTANCE control is increased from full CCW position. Null may not be deep at this point. If null is not apparent, reduce setting of SERIES CAP. a bit and try again.

6.) With INDUCTANCE set for best null, try to deepen null with SERIES CAP. If rotating this control CCW from 10 position causes meter deflection to increase, set INDUCTANCE control one step clockwise and try dipping with SHUNT CAP. again. Continue until SHUNT CAP. can provide a null near its full maximum position. Adjust transmitter drive to provide adequate meter deflection.

7.) If null produced is not 1 to 1 with rated drive, decrease setting of SERIES CAP. a bit and renull with SHUNT CAP. Continue this procedure until 1 to 1 reading is obtained with full drive, or best null below 2 to 1 is attained. (If by decreasing SERIES CAP. resonance is not attainable with SHUNT CAP., increase INDUCTANCE one more notch and retune capacitors.

8.) To accurately determine if SWR is sufficientle low, set FWD. meter deflection to indexed mark on meter with SENSITIVITY control and read SWR in REV. switch position. Reading below 2 is acceptable.

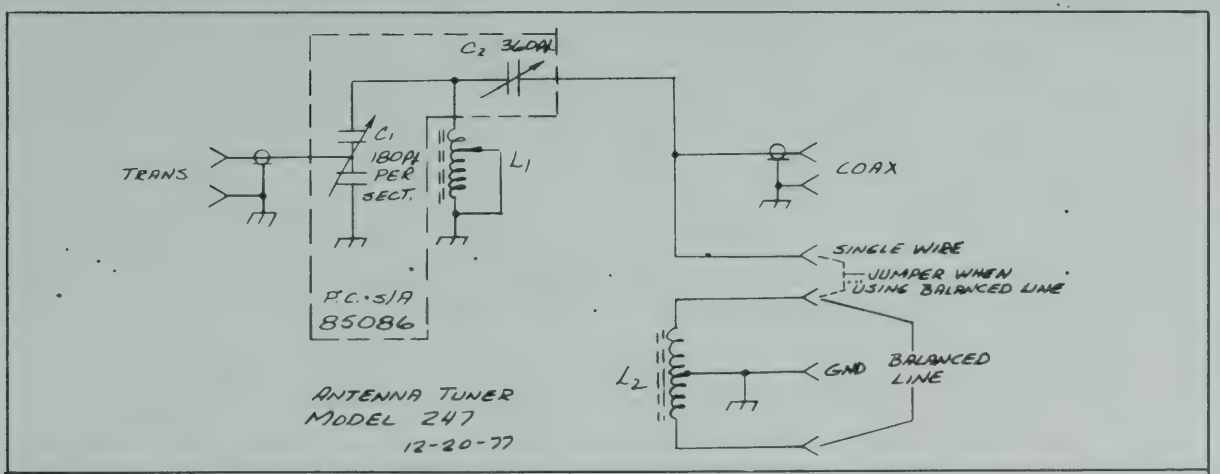
9.) It is good procedure to leave SWR meter in REV. position so that you can monitor match while operating. If you tune too far from resonance, it will be apparent and retuning can be initiated.

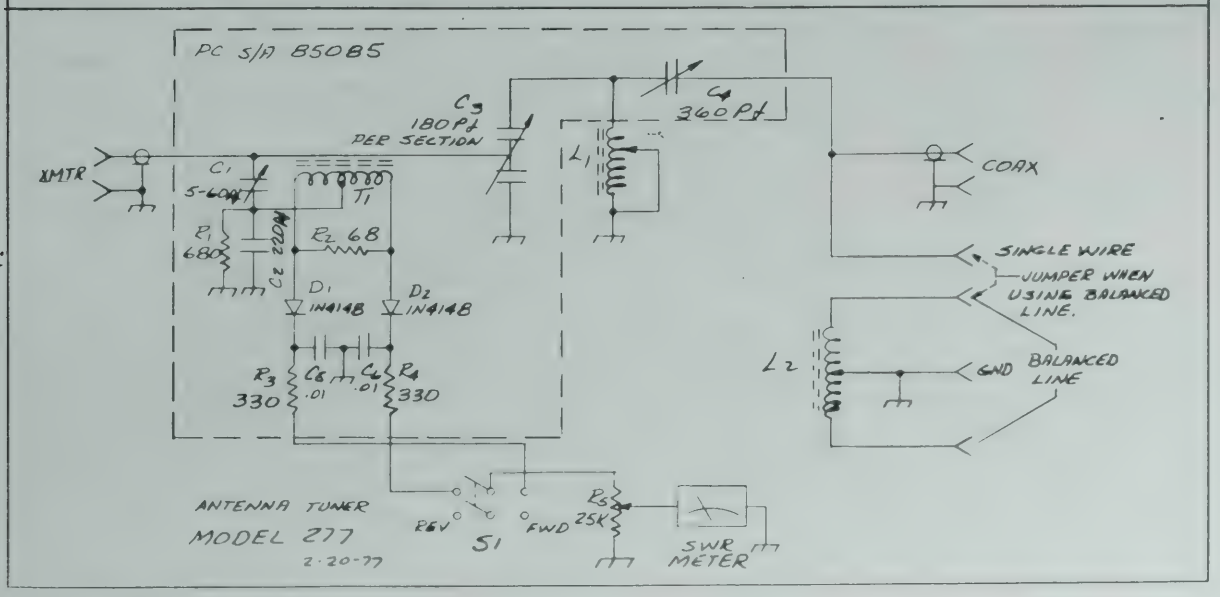
10.) It is convenient to record control settings for each band of operation and possibly at 3.6 and 3.9 MHz of 80 meter band. Then tune-up will be simplified when changing bands because starting points will already be established.

Approximate starting points for control settings for each band are given in Table I below. These guideline settings require some alteration for your specific antenna systems, and exact settings should be determined using the procedures outlined above. Reactive loads will alter the values somewhat, but mainly in the SERIES CAP. columns.

TABLE I
GUIDELINE CONTROL SETTINGS

FREQ. MHz	UNBALANCED COAXIAL FEED SYSTEMS									SINGLE WIRE			BALANCED LINE		
	50 OHMS			150 OHMS			17 OHMS			800 OHMS			300 OHMS		
	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.
1.8	7	10	38	7	10	44	10	10	29	-	-	-	8	10	34
3.6	7	10	15	7	10	17	9	10	11	10	10	23	6	10	16
3.9	7	10	13	7	10	15	9	10	10	10	10	21	6	10	14
7.1	6	10	6	7	9	7	7	10	5	10	7	12	5	10	7
14.2	4	9	3	6	7	3	4	10	2	10	5	6	4	10	3
21.2	2	8	2	5	9	1	1	7	2	10	3	4	3	7	2
28.5	1	7	1	2	5	1	0	9	1	10	2	3	3	7	1





TEN-TEC, INC.
Sevierville, TN 37862

REPAIR DEPARTMENT TELEPHONE
615-428-0364

LIMITED WARRANTY AND SERVICE POLICY

TEN-TEC, INC. warrants all products to be free from defects in material and workmanship for a period of one year after date of purchase, under these conditions:

1.) Registration: The warranty card must be returned promptly to establish the warranty period. Our card file also serves as a check on stolen equipment which may be sent in for repair. Please notify us immediately if your TEN-TEC equpment is stolen.

2.) Original Purchaser: This warranty applies only to the original purchaser. Your returned warranty card listing from whom purchased establishes you as the original purchaser.

3.) Communication with the Factory: If trouble develops, contact your TEN-TEC dealer from whom you purchased the unit. He is obligated to try to correct the malfunction or return the unit to us. If he is unable to correct the fault, you or the dealer should contact the factory by mail or by telephone 615-428-0364, giving serial number if assigned, symptoms of fault and conditions under which they appear. You will be advised whether to return the unit to us or to try a replacement plug-in assembly that will be sent to you. To facilitate service calls, please use our direct Repair Department telephone number, 615-428-0364. (NO COLLECT CALLS, PLEASE.)

4.) In-Warranty Field Repairs: To expedite repairs TEN-TEC will send replacement assemblies prior to receiving the suspected defective one from you. The replacement will be billed on a 30 day memo, and credit will be issued when the defective unit is returned to us. No remittance or deposit is required. If the defective assembly is not returned within 30 days, you will be billed.

5.) Return to Non-Selling Dealer: If you return the in-warranty unit to an authorized TEN-TEC dealer who did not sell the unit to you, he may, at his option, repair the unit or handle the return to the factory. Under these conditions TEN-TEC will repair or replace all defective components without charge, but reasonable labor charges may be levied by the servicing dealer. TEN-TEC is not liable for labor charges under these conditions.

6.) Proper Delivery: If the unit is returned to the factory, it must be adequately packed. A note should be included outlining the problem, conditions under which it appears, and attempted remedies. The more specific you are, the better the possibility of a complete fix. Shipping charges to the factory are to be borne by you. Unit will be returned, transportation paid by TEN-TEC.

7.) Extended Pro-Rata Warranty on Models 540/544/545/546 Output Transistors: The output transistors on these models are unconditionally guaranteed against damage for a period of one year after date of purchase, under any load condition or mode of operation, except for static discharge on the antenna or direct lightning strike. If they fail after the warranty period, the following replacement schedule will apply, provided that our service department makes the repair. (Prices listed are maximum and subject to reduction, depending on current transistor prices at time of repair.)

1 to 2 years	2 to 3 years	3 to 5 years
$12.00 each	$15.00 each	$18.00 each

(Two transistors per transceiver. Labor not included.)

8.) Exclusions: This warranty does not apply to damage caused by mishandling, lightning, voltages in excess of rating, reverse polarity of DC supply, or changes in circuits. Claims for damage in transit should be filed with the carrier. This warranty, however, is NOT voided for attempted repairs of defective units, or for incorporation of additional components such as switches, etc. when there is no change in the basic circuit. Under no circumstances is TEN-TEC liable for consequential damage to person or property by use of this unit.

9.) TEN-TEC reserves the right to make any improvements to its products which it may deem desirable without obligating itself to install such improvements in its previously manufactured products.

10.) This warranty is given in lieu of any other warranty expressed or implied.

Out-of-Warranty Repairs

1.) Field Repairs: New circuit boards or discrete components can often be supplied to eliminate the cost and bother of shipping the complete unit to us. A nominal charge will be made for the material sent. Certain assemblies intregal with the main chassis, such as VFO assemblies and rack tuning mechanisms, are not field replaceable.

2.) Returned Units: Along with the unit, please submit a complete report on the nature of the malfunction and the conditions under which it occurs. This will enable our service department to pay special attention to your problem area and reduce overall labor costs. No matter what the malfunction is, every unit will be given a complete alignment and operational check before being returned.

3.) Quotations: Quotations on repair work will be given on request, after examination of the unit. The amount quoted will be firm for the specific work outlined in the quotation. Should additional material or labor requirements come to light after the repair is initiated, you will be contacted for approval before this phase of the repair is started.

4.) Repair Charge Payment: Charges below the $25.00 level will be billed to you after completion of the work and at the time of re-shipment. A report of all work done and parts used will accompany the bill. For charges greater than $25.00, prepayment will be required before the unit is returned. One of three methods of payment may be selected. 1.) Upon completion of the work the billing will be made but the unit will be held here. Upon receipt of the payment, the unit will be shipped. 2.) The unit will be returned to you on a COD basis, with COD charges borne by you. 3.) The repair charges may be paid by either MasterCharge or BankAmericard/VISA.

Approval for COD or charge card options can be given either at the time the unit is submitted to us (in the accompanying letter) or when contacted upon completion of the repair. Please submit all raised information on your charge card when paying by this means.

5.) Transportation Charges: Units should be returned, transportation and insurance charges prepaid. Return transportation and insurance charges will be billed to you with other costs.

TEN-TEC MODELS 247 & 277 ANTENNA TUNERS

GENERAL

Models 247 and 277 Antenna Tuners are inductive/capacitive networks used for matching unbalanced 50-75 ohm output impedances of transmitters and transceivers to a variety of loads, both balanced and unbalanced. They operate over a frequency range of 1.8 to 30 MHz. Both incorporate the universal Transmatch circuit. Model 277 has, in addition to the tuner components, a built-in SWR bridge and meter.

SPECIFICATIONS

Circuit: Universal Transmatch.
Rf Power: 100 watts, continuous: 200 watts, intermittent.
Capacitor Voltage Rating: 1 kV.
Toroid: 47 tap, 18 guage silver plated wire on 2" diameter core.
Input Impedance: 50-75 ohms.
Output: Matches all loads, balanced and unbalanced. Maximum balanced load 1.8 to 4.0 MHz is 600 ohms.
Frequency Range: 1.8 to 30 MHz.

Model 247 Only:

Finish: Etched aluminum chassis and front panel; black textured sides and top.
Size: HWD 2-15/16" x 7-3/4" x 6-11/16".
Weight: 3 lbs.

Model 277 Only:

Meter: SWR bridge with forward/reverse switch.
Finish: Grey chassis and front panel; black textured sides and top.
Size: HWD 3-1/2" x 10-1/4" x 6-1/2".
Weight: 3 lbs.

INSTALLATION

1.) Connect coaxial output of transmitter to coaxial input of tuner with short length of RG-8 or RG-58 cable. Connectors are PL-259 types. Notice: To reduce possibility of rf from getting into transmitter, position tuner as far away from transmitter as is practical. Never set tuner directly on top of transmitter.

2.) Connect station ground buss to terminal on tuner marked GND with heavy metalic braid or wire. This lead should go directly to the earth ground system with as short a lead as possible.

3.) Connect transmission line to appropiate terminals on tuner as follows:

A.) For unbalanced transmission lines, use connector labeled COAX and coaxial type cable. Do not connect jumper between SINGLE WIRE and one BALANCED LINE terminal.

B.) For single wire feeds, connect line to SINGLE WIRE terminal.

C.) For balanced line feed systems, first jumper terminals indicated, SINGLE WIRE and one BALANCED LINE, with short wire. Connect feed line to two BALANCED LINE terminals.

In both single wire and balanced line systems, take special care to route transmission line as far away from station equipment as possible. Never drape lines over transmitter. These lines may have a high voltage point inside the shack which presents high rf fields.

4.) If your tuner is Model 247 and no bridge is incorporated in the transmitter, insert a SWR bridge in series with the lead between transmitter output and tuner input. Do not place bridge in output line of tuner. SWR bridge is necessary for proper tuner adjustment. (When using Model 240 One Sixty Converter with TEN-TEC Models 540/544 tranceiver, SWR bridge in transceiver cannot be used on 160 meter band for tuner adjustment. Either Model 277 with SWR bridge incorporated or a separate bridge inserted in line between Model 240 output and antenna tuner input must be used.)

ANTENNA SYSTEMS MATCHING THEORY

Most transmitters are designed to work into a 50-75 ohm resistive load, and they are not able to effectively supply rf power to loads that depart far from these values. However, many antenna systems, which include the antenna and the transmission line, have complex impedances that make it difficult if not impossible to load the transmitter properly. These impedances are a function of the operating frequency, type of antenna, type and length of transmission line, height of antenna and its proximity to other objects.

Models 247/277 provide a coupling method to convert the resistive/reactive load to a pure resistance of 50 ohms that will accept maximum power from the transmitter. This is not to say that any and all antennas, when converted to a 50 ohm resistive impedance by means of a tuner, will give identical performance. To best understand the tuner adjustments required, it is necessary to have a fundamental knowledge of how antenna systems function. To this end, a short technical discussion follows. It is recommended that additional reading on the subject be made by those interested in obtaining maximum performance from their antenna systems. The ARRL Antenna Handbook, ARRL Amateur's Radio Handbook (antenna and transmission line sections) and other antenna books published by the publishers of Amateur Radio magazines are excellent sources of information. For those already versed in antenna theory, skip down to the OPERATION section.

THE ANTENNA - Any conductor that has rf currents flowing in it can be looked on as an antenna or radiator. The extent to which power leaves the conductor and radiates into the surrounding medium depends on many factors -- length, frequency, amount of current, configuration, etc. Since the antenna absorbs power from the device feeding it, it can be replaced with a resistance whose value is such that the power delivered to this resistance is the same as that delivered to the antenna. The value of this resistance is now a measure of the radiating effectiveness of the antenna and is termed "radiation resistance". For a given value of antenna current, the higher this resistance, the more power that is radiated. ($P=I^2R$)

Due to the facts that an antenna has physical length, that currents travel at a velocity less than instantaneous and that the conductor posseses a certain amount of self inductance and capacitance, the current at the feed point may not be in phase with the voltage at this point. As a result, the impedance at this point may not look like the pure resistance first suspected, but as an impedance consisting of resistance and either inductive or capacitive reactance. This added reactance will limit the amount of current supplied to the antenna for a given voltage, and therefore reduce the amount of radiated power. The reactance does not absorb power in itself -- only a resistance can do that -- but its presence reduces the overall radiated power and antenna current.

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In the above example, we used a value of 50 ohms for the radiation resistance. If this value were not 50 but 150 ohms, the impedance after cancelling the reactance out would be 150 ohms. Connecting this load to the transmitterdesigned to operate with 50 ohms load would not result in optimum power transfer. It would, however, be better than leaving the inductive reactance in, since the antenna current is maximized for the conditions that do exist. To obtain design performance, it is necessary to transform the 150 ohms to 50. This can be done with a transformer with a turns ratio of 1.73 to 1. (Impedance transformation is equal to the square of the turns ratio.) It is also possible to accomplish this transformation with a parallel tuned circuit with primary and secondary taps properly located on the inductor, or using two or more capacitors in series with taps taken from the series string. Under these conditions, the transceiver will deliver rated power to the antenna.

One last observation before we go on. The antenna impedance in the above example was stated as that at the feed point. If we now feed the antenna at a different location along the conductor, the impedance will be different, both resistive and reactive components. There are an infinite number of impedance choices available, depending on where the tap is made. This factor is helpful in designing and matching antennas. The factors that determine this impedance are the current and voltage values at this point, and the phase between them.

THE TRANSMISSION LINE - In the above example, we assumed that the transmitter output was connected directly to the feed point. This is hardly practical. So that the transmitter can be located at a distance from the antenna, we use a transmission line to deliver the power. Unless we have a perfectly matched system, i.e. antenna, line and transmitter output impedances all the same value without reactive components, the addition of the transmission line completely changes the picture. The transmitter will not see the antenna impedance of 50 ohms resistive and 100 ohms inductive reactance, but some other combination. It will depend on the electrical length of the line, its characteristic impedance and frequency. The impedance at the transmitter end is what we are interested in, and the inductive component may even be changed to capacitance. (Only when the electrical length of the line is an exact multiple of the half wavelength will the impedance at the transmitter be the same as the antenna impedance.)

Briefly, the line characteristic impedance is determined by the physical dimensions of the line -- wire diameter and spacing -- and the dielectric of the material in between. The wire also posseses a resistive component which will dissipate power when current flows through it to the antenna. This shows up as heat loss and dictates use of low loss cable. Formulas for coax and open wire line impedances are given in the handbooks.

Since rf currents flow in the transmission line, one may ask if it then becomes an antenna. In the case of coax type lines, the current should flow on the inside surface of the outer conductor and outer surface of the inner conductor. The electric and magnetic fields caused by the current flow are confined between the two, so none can escape and be radiated. If a system configuration results in some rf current flowing on the outer surface of the outer conductor, such as when a dipole is fed with coax without a balun or other means of changing the feed line from an unbalanced to balanced configuration, it will radiate power. In the case of parallel lines, the current in one conductor at a given location should be flowing in the opposite direction to the current in the adjacent conductor, and if the system is well balanced, the amplitudes of the two will be equal. Under these conditions, the two sets of fields exactly cancel each other and very little radiation will result. If the two currents are not equal or not in exact opposite phase, there will be radiation. Also, if the spacing between lines is a considerable portion of the wavelength, radiation will occur. This is not a factor below VHF.

One final characteristic of transmission lines should be mentioned. The rf current flowing in the line travels at a speed less than that of radiated power in a vacuum, or the speed of light, both 186,000 miles per second. This slowing is caused by the dielectric property of the medium through which the field traverses. In coax cables it is polyethelene between inner and outer conductors, and in parallel lines, it may be the plastic between the conductors in the case of twin-lead type line, or the air and plastic spacers in open wire

types. The ratio of the speed in the line to the speed in a vacuum (air is almost the same) is called the velocity factor of the cable. It is always less than unity. Because of this slowing, the physical length of a transmission line is not the same as the electrical length. For example, the wavelength in free space of a 30 MHz signal is exactly 10 meters. A transmission line 10 meters long will be one full wavelength only if the dielectric between the conductors is air. In the case of coax cable with polyethelene dielectric, the velocity factor runs about 0.67. The same 10 meter length of cable will now appear electrically as an open wire or air dielectric cable 15 meters long (10 divided by 0.67). This is equivalent to one and one half wavelengths. A polyethelene type cable would only have to be 6.7 meters long to be one wavelength.

EFFECT OF TRANSMISSION LINE ON ANTENNA IMPEDANCE - As a result of all of the above, in situations where we do not have a matched system throughout, and this is most of the time, the impedance presented to the transmission line by the antenna sets up standing waves on the line. These standing waves will alter the antenna impedance all along the line toward the transmitter. What we really want to accomplish with the antenna tuner is to take whatever impedance that is established at the transmitter end of the line and alter it to a 50 ohm resistance. Then the transmitter will be happy, at least. The tuner will not affect the mismatch of antenna to line -- only constructing the antenna differently will do that --nor eliminate a standing wave on the transmission line. It will eliminate a standing wave on the line between transmitter and tuner input, but not on the output side of the tuner. A good antenna is still needed to "get out". If the antenna has a low resistance, the tuner will transform it, along with the cable loss resistance, to 50 ohms. The full power will enter the system, but it will be divided between radiation and cable heat loss. It is not uncommon that more than half of the available power is wasted in cable losses, even with low loss cable. It just gets a bit hotter. The split depends entirely on the ratio of radiation resistance to loss resistance.

What is the impedance established at the transmitter end of the line? It depends first on the antenna impedance, which is then transformed by the line. This transformation is dependent on frequency, electrical length of the line and the loss in the line. In an Amateur setup where many different frequencies are used with the same antenna, there will be a multitude of impedances presented to the tuner, so adjustment of the matching network will be required as frequency is changed.

STANDING WAVE RATIO - A measure of how badly a system is mismatched is given by the standing wave ratio (SWR) on the line. SWR is the ratio of the maximum voltage encountered along a transmission line greater than one half wavelength long to the minimum voltage. It is also the ratio of maximum to minimum current. The more nearly uniform the voltage distribution along the line, the closer matched it is, and the ultimate is when the voltage is constant down the length of a lossless line, or drops slowly and uniformly along a line with losses. This is the matched condition, represented by a 1 to 1 SWR. The impedance at the load end of such a line is the same as that at the generator end. When adjusting a matching network properly, the way to do it is to observe the SWR and tune for as low a ratio as possible.

The SWR is also an indication of the value of resistance at the load end. The ratio is the same as the ratio of load resistance to line characteristic impedance. This ratio can mean that the load is either greater than or less than the line's impedance. For example, if the SWR on a length of 50 ohm line is 3 to 1, the load resistance is either 150 ohms or 16.7 ohms (3 times 50 or one third of 50). This is only accurate with pure resistive loads.

It can be shown mathematically that a 2 to 1 SWR in a system which has the transmitter output impedance equal to the line impedance delivers 89% of the power to the load that it would if perfectly matched. This relates to a power loss of half a decibel -- hardly noticeable in signal strength. At a 3 to 1 ratio, the loss becomes appreciable with 25% of the power lost. So in adjusting antenna tuners, it is a nice feeling if you achieve a 1 to 1 match, but in reality, anything below 2 to 1 is satisfactory. Line losses do increase a bit also with increasing SWR, but it is still a small fraction of a dB at 2:1.

TRANSMATCH TUNER CIRCUIT - A look at the schematic reveals that the circuit used in TEN-TEC tuners consists of a parallel circuit of inductor L1 and two variable capacitors connected in series. The input is applied to the center of the series capacitors and ground. Another variable capacitor is connected in series with the output lead to the COAX and SINGLE WIRE terminals. For ballanced outputs, balun L2 is connected so that the basic tuner output is applied to one half of the winding, and transformer action produces the opposite half with reference to chassis ground. Hence the balanced output will provide twice the rf voltage, symetrical to ground. The impedance transformation with this arrangement is a step-up of four times on the antenna side. This circuit should match just about any antenna system impedance to 50 ohms.

When the circuit is tuned for a match, the parallel tuned circuit will be approximately in resonance at the frequency involved. Reactive components in the load will be compensated for by both the series output capacitor and a slight off-resonance setting of the parallel circuit. It will be noted that since both inductor and shunt capacitor are variable, there are many possible settings of these components that will resonate at a given frequency. A high inductance with small capacitance will resonate just as well as a small inductance with large capacitor. Is one way better than the other? The answer is yes. When matching to high impedances, there must be a certain amount of inductance present before a match is achievable. The step up transformation of resistance is dependent on the "Q" of the circuit, which is a function of the inductance. In addition, the frequency range over which operation with acceptable SWR is possible without retuning is dependent on the L to C ratio of the circuit. The smaller this ratio, the greater the bandwidth. (To illustrate how effective this becomes at low frequencies, the following results from lab tests at 3.75 MHz and a 50 ohm load were obtained: With maximum L/C ratio, i.e. INDUCTANCE setting of 47 and SHUNT CAP. about 3.2, the frequency range before a SWR of 2 to 1 was encountered was 50 kHz, $\pm$ 25 kHz on either side of the center frequency. Using the lowest L/C ratio, INDUCTANCE set to 14 and SHUNT CAP. to 10, range increased to over 400 kHz, almost the entire 80 meter band.) With the broader band L/C ratio, tuner adjustments become less critical and the SWR meter dip to 1 to 1 is broad. With high L/C ratios, the dip is very narrow and sharp, and it may be easily overlooked.

To summarize the above: Best and broadest operation is obtained when SHUNT CAP. is set to maximum possible setting that will allow a match to 1 to 1. Under these conditions, INDUCTANCE will be minimum at which resonance can be attained. SERIES CAP. is primarily used when reactive components need cancelling out. With single wire resistive antenna, SERIES CAP. setting will be near maximum.

OVERALL SUMMARY

1.) Any antenna can be represented as an equivalent resistive/reactive impedance whose resistive component, termed radiation resistance, is a measure of the power radiated. Reactance can be either inductive or capacitive.

2.) Antenna impedance is a function of frequency, configuration, selection of feed point location, height above ground and nearness to surrounding objects.

3.) The reactive portion of the impedance does not absorb power but limits the amount of power radiated by the resistive component. It is best to eliminate the reactive component, by inserting an equal value reactance in series, but of the opposite type.

4.) Best system performance is attained when antenna impedance is purely resistive with value equal to transmission line impedance, which in turn equals transmitter output impedance.

5.) Since antennas seldom present matched impedances to line over a band of frequencies and from band to band, a partial solution to using these mismatched systems is to convert the impedances at the transmitter end of the line to what the transmitter is designed for, with an antenna tuner.

6.) The transmission line will change the antenna impedance in both resistive and reactive values at the transmitter end, depending on the line's

electrical length, frequency and characteristic impedance.

7.) Due to slowing down of the current flow in the transmission line from that in free space, the electrical length of a line will be longer than the physical length.

8.) One special situation where the line does not alter the impedance is when its length is an exact multiple of the electrical have wavelength.

9.) An antenna tuner will not affect the antenna impedance nor the standing wave condition on the transmission line. It will correct the SWR on that portion of the line between transmitter output and tuner input, so that the transmitter will supply rated power to the system.

10.) Standing wave ratio, SWR, is a measure of the mis-match of the system and is used as the indicator when making tuner adjustments. SWR is direct ratio ofload resistance to line's characteristic impedance.

11.) SWR other than 1 to 1 indicates two possible impedances, one greater and one less than characteristic impedance.

12.) Any SWR value less than 2 to 1 is considered a good match.

13.) Transmatch tuner circuit can provide a number of different control settings, all of which produce a match. Difference is in L to C ratio of the tuned circuit.

14.) The lowest L/C ratio will provide greatest bandwidth for a given SWR limit. If adjusted for maximum bandwidth, retuning across the band will only be necessary on 160 and 80 meters, and possibly on extremes of 40 meter band.

OPERATION

1.) Always make tuner adjustments with minimum required power from transmitter. To do this, set sensitivity of SWR bridge to maximum, fully CW on Model 277.

2.) Set up meter to read SWR. This is REV. switch position on Model 277.

3.) Set both SERIES CAP. and SHUNT CAP. fully clockwise, (10 position).

4.) Apply just enough drive to transmitter so that meter reading is approximately half scale.

5.) Attempt to find a null as INDUCTANCE control is increased from full CCW position. Null may not be deep at this point. If null is not apparent, reduce setting of SERIES CAP. a bit and try again.

6.) With INDUCTANCE set for best null, try to deepen null with SERIES CAP. If rotating this control CCW from 10 position causes meter deflection to increase, set INDUCTANCE control one step clockwise and try dipping with SHUNT CAP. again. Continue until SHUNT CAP. can provide a null near its full maximum position. Adjust transmitter drive to provide adequate meter deflection.

7.) If null produced is not 1 to 1 with rated drive, decrease setting of SERIES CAP. a bit and renull with SHUNT CAP. Continue this procedure until 1 to 1 reading is obtained with full drive, or best null below 2 to 1 is attained. (If by decreasing SERIES CAP. resonance is not attainable with SHUNT CAP., increase INDUCTANCE one more notch and retune capacitors.

8.) To accurately determine if SWR is sufficientle low, set FWD. meter deflection to indexed mark on meter with SENSITIVITY control and read SWR in REV. switch position. Reading below 2 is acceptable.

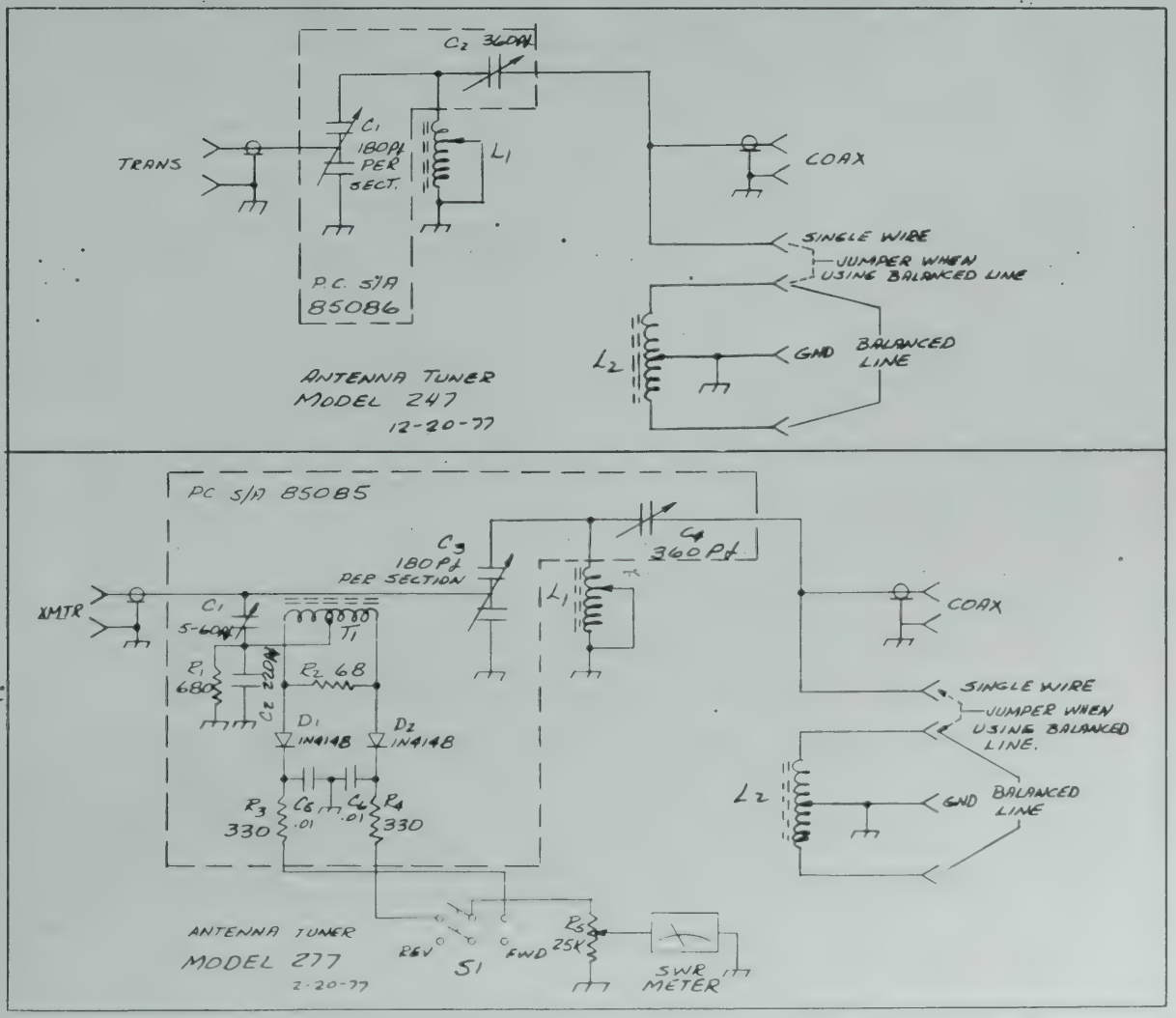
9.) It is good procedure to leave SWR meter in REV. position so that you can monitor match while operating. If you tune too far from resonance, it will be apparent and retuning can be initiated.

10.) It is convenient to record control settings for each band of operation and possibly at 3.6 and 3.9 MHz of 80 meter band. Then tune-up will be simplified when changing bands because starting points will already be established.

Approximate starting points for control settings for each band are given in Table I below. These guideline settings require some alteration for your specific antenna systems, and exact settings should be determined using the procedures outlined above. Reactive loads will alter the values somewhat, but mainly in the SERIES CAP. columns.

TABLE I
GUIDELINE CONTROL SETTINGS

FREQ. MHz	UNBALANCED COAXIAL FEED SYSTEMS									SINGLE WIRE			BALANCED LINE		
	50 OHMS			150 OHMS			17 OHMS			800 OHMS			300 OHMS		
	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.
1.8	7	10	38	7	10	44	10	10	29	-	-	-	8	10	34
3.6	7	10	15	7	10	17	9	10	11	10	10	23	6	10	16
3.9	7	10	13	7	10	15	9	10	10	10	10	21	6	10	14
7.1	6	10	6	7	9	7	7	10	5	10	7	12	5	10	7
14.2	4	9	3	6	7	3	4	10	2	10	5	6	4	10	3
21.2	2	8	2	5	9	1	1	7	2	10	3	4	3	7	2
28.5	1	7	1	2	5	1	0	9	1	10	2	3	3	7	1



TEN-TEC, INC.
Sevierville, TN 37862

REPAIR DEPARTMENT TELEPHONE
615-428-0364

LIMITED WARRANTY AND SERVICE POLICY

TEN-TEC, INC. warrants all products to be free from defects in material and workmanship for a period of one year after date of purchase, under these conditions:

1.) Registration: The warranty card must be returned promptly to establish the warranty period. Our card file also serves as a check on stolen equipment which may be sent in for repair. Please notify us immediately if your TEN-TEC equpment is stolen.

2.) Original Purchaser: This warranty applies only to the original purchaser. Your returned warranty card listing from whom purchased establishes you as the original purchaser.

3.) Communication with the Factory: If trouble develops, contact your TEN-TEC dealer from whom you purchased the unit. He is obligated to try to correct the malfunction or return the unit to us. If he is unable to correct the fault, you or the dealer should contact the factory by mail or by telephone 615-428-0364, giving serial number if assigned, symptoms of fault and conditions under which they appear. You will be advised whether to return the unit to us or to try a replacement plug-in assembly that will be sent to you. To facilitate service calls, please use our direct Repair Department telephone number, 615-428-0364. (NO COLLECT CALLS, PLEASE.)

4.) In-Warranty Field Repairs: To expedite repairs TEN-TEC will send replacement assemblies prior to receiving the suspected defective one from you. The replacement will be billed on a 30 day memo, and credit will be issued when the defective unit is returned to us. No remittance or deposit is required. If the defective assembly is not returned within 30 days, you will be billed.

5.) Return to Non-Selling Dealer: If you return the in-warranty unit to an authorized TEN-TEC dealer who did not sell the unit to you, he may, at his option, repair the unit or handle the return to the factory. Under these conditions TEN-TEC will repair or replace all defective components without charge, but reasonable labor charges may be levied by the servicing dealer. TEN-TEC is not liable for labor charges under these conditions.

6.) Proper Delivery: If the unit is returned to the factory, it must be adequately packed. A note should be included outlining the problem, conditions under which it appears, and attempted remedies. The more specific you are, the better the possibility of a complete fix. Shipping charges to the factory are to be borne by you. Unit will be returned, transportation paid by TEN-TEC.

7.) Extended Pro-Rata Warranty on Models 540/544/545/546 Output Transistors: The output transistors on these models are unconditionally guaranteed against damage for a period of one year after date of purchase, under any load condition or mode of operation, except for static discharge on the antenna or direct lightning strike. If they fail after the warranty period, the following replacement schedule will apply, provided that our service department makes the repair. (Prices listed are maximum and subject to reduction, depending on current transistor prices at time of repair.)

1 to 2 years	2 to 3 years	3 to 5 years
$12.00 each	$15.00 each	$18.00 each

(Two transistors per transceiver. Labor not included.)

8.) Exclusions: This warranty does not apply to damage caused by mishandling, lightning, voltages in excess of rating, reverse polarity of DC supply, or changes in circuits. Claims for damage in transit should be filed with the carrier. This warranty, however, is NOT voided for attempted repairs of defective units, or for incorporation of additional components such as switches, etc. when there is no change in the basic circuit. Under no circumstances is TEN-TEC liable for consequential damage to person or property by use of this unit.

9.) TEN-TEC reserves the right to make any improvements to its products which it may deem desirable without obligating itself to install such improvements in its previously manufactured products.

10.) This warranty is given in lieu of any other warranty expressed or implied.

Out-of-Warranty Repairs

1.) Field Repairs: New circuit boards or discrete components can often be supplied to eliminate the cost and bother of shipping the complete unit to us. A nominal charge will be made for the material sent. Certain assemblies intregal with the main chassis, such as VFO assemblies and rack tuning mechanisms, are not field replaceable.

2.) Returned Units: Along with the unit, please submit a complete report on the nature of the malfunction and the conditions under which it occurs. This will enable our service department to pay special attention to your problem area and reduce overall labor costs. No matter what the malfunction is, every unit will be given a complete alignment and operational check before being returned.

3.) Quotations: Quotations on repair work will be given on request, after examination of the unit. The amount quoted will be firm for the specific work outlined in the quotation. Should additional material or labor requirements come to light after the repair is initiated, you will be contacted for approval before this phase of the repair is started.

4.) Repair Charge Payment: Charges below the $25.00 level will be billed to you after completion of the work and at the time of re-shipment. A report of all work done and parts used will accompany the bill. For charges greater than $25.00, prepayment will be required before the unit is returned. One of three methods of payment may be selected. 1.) Upon completion of the work the billing will be made but the unit will be held here. Upon receipt of the payment, the unit will be shipped. 2.) The unit will be returned to you on a COD basis, with COD charges borne by you. 3.) The repair charges may be paid by either MasterCharge or BankAmericard/VISA.

Approval for COD or charge card options can be given either at the time the unit is submitted to us (in the accompanying letter) or when contacted upon completion of the repair. Please submit all raised information on your charge card when paying by this means.

5.) Transportation Charges: Units should be returned, transportation and insurance charges prepaid. Return transportation and insurance charges will be billed to you with other costs.

TEN-TEC MODELS 247 & 277 ANTENNA TUNERS

GENERAL

Models 247 and 277 Antenna Tuners are inductive/capacitive networks used for matching unbalanced 50-75 ohm output impedances of transmitters and transceivers to a variety of loads, both balanced and unbalanced. They operate over a frequency range of 1.8 to 30 MHz. Both incorporate the universal Transmatch circuit. Model 277 has, in addition to the tuner components, a built-in SWR bridge and meter.

SPECIFICATIONS

Circuit: Universal Transmatch.
Rf Power: 100 watts, continuous: 200 watts, intermittent.
Capacitor Voltage Rating: 1 kV.
Toroid: 47 tap, 18 guage silver plated wire on 2" diameter core.
Input Impedance: 50-75 ohms.
Output: Matches all loads, balanced and unbalanced. Maximum balanced load 1.8 to 4.0 MHz is 600 ohms.
Frequency Range: 1.8 to 30 MHz.

Model 247 Only:

Finish: Etched aluminum chassis and front panel; black textured sides and top.
Size: HWD 2-15/16" x 7-3/4" x 6-11/16".
Weight: 3 lbs.

Model 277 Only:

Meter: SWR bridge with forward/reverse switch.
Finish: Grey chassis and front panel; black textured sides and top.
Size: HWD 3-1/2" x 10-1/4" x 6-1/2".
Weight: 3 lbs.

INSTALLATION

1.) Connect coaxial output of transmitter to coaxial input of tuner with short length of RG-8 or RG-58 cable. Connectors are PL-259 types. Notice: To reduce possibility of rf from getting into transmitter, position tuner as far away from transmitter as is practical. Never set tuner directly on top of transmitter.

2.) Connect station ground buss to terminal on tuner marked GND with heavy metalic braid or wire. This lead should go directly to the earth ground system with as short a lead as possible.

3.) Connect transmission line to appropiate terminals on tuner as follows:

A.) For unbalanced transmission lines, use connector labeled COAX and coaxial type cable. Do not connect jumper between SINGLE WIRE and one BALANCED LINE terminal.

B.) For single wire feeds, connect line to SINGLE WIRE terminal.

C.) For balanced line feed systems, first jumper terminals indicated, SINGLE WIRE and one BALANCED LINE, with short wire. Connect feed line to two BALANCED LINE terminals.

In both single wire and balanced line systems, take special care to route transmission line as far away from station equipment as possible. Never drape lines over transmitter. These lines may have a high voltage point inside the shack which presents high rf fields.

4.) If your tuner is Model 247 and no bridge is incorporated in the transmitter, insert a SWR bridge in series with the lead between transmitter output and tuner input. Do not place bridge in output line of tuner. SWR bridge is necessary for proper tuner adjustment. (When using Model 240 One Sixty Converter with TEN-TEC Models 540/544 tranceiver, SWR bridge in transceiver cannot be used on 160 meter band for tuner adjustment. Either Model 277 with SWR bridge incorporated or a separate bridge inserted in line between Model 240 output and antenna tuner input must be used.)

ANTENNA SYSTEMS MATCHING THEORY

Most transmitters are designed to work into a 50-75 ohm resistive load, and they are not able to effectively supply rf power to loads that depart far from these values. However, many antenna systems, which include the antenna and the transmission line, have complex impedances that make it difficult if not impossible to load the transmitter properly. These impedances are a function of the operating frequency, type of antenna, type and length of transmission line, height of antenna and its proximity to other objects.

Models 247/277 provide a coupling method to convert the resistive/reactive load to a pure resistance of 50 ohms that will accept maximum power from the transmitter. This is not to say that any and all antennas, when converted to a 50 ohm resistive impedance by means of a tuner, will give identical performance. To best understand the tuner adjustments required, it is necessary to have a fundamental knowledge of how antenna systems function. To this end, a short technical discussion follows. It is recommended that additional reading on the subject be made by those interested in obtaining maximum performance from their antenna systems. The ARRL Antenna Handbook, ARRL Amateur's Radio Handbook (antenna and transmission line sections) and other antenna books published by the publishers of Amateur Radio magazines are excellent sources of information. For those already versed in antenna theory, skip down to the OPERATION section.

THE ANTENNA - Any conductor that has rf currents flowing in it can be looked on as an antenna or radiator. The extent to which power leaves the conductor and radiates into the surrounding medium depends on many factors -- length, frequency, amount of current, configuration, etc. Since the antenna absorbs power from the device feeding it, it can be replaced with a resistance whose value is such that the power delivered to this resistance is the same as that delivered to the antenna. The value of this resistance is now a measure of the radiating effectiveness of the antenna and is termed "radiation resistance". For a given value of antenna current, the higher this resistance, the more power that is radiated. ($P=I^2R$)

Due to the facts that an antenna has physical length, that currents travel at a velocity less than instantaneous and that the conductor posseses a certain amount of self inductance and capacitance, the current at the feed point may not be in phase with the voltage at this point. As a result, the impedance at this point may not look like the pure resistance first suspected, but as an impedance consisting of resistance and either inductive or capacitive reactance. This added reactance will limit the amount of current supplied to the antenna for a given voltage, and therefore reduce the amount of radiated power. The reactance does not absorb power in itself -- only a resistance can do that -- but its presence reduces the overall radiated power and antenna current.

There are two ways to restore the power to its non-reactive value. The first, which is not the preferred way because it does not maximize power transfer, is to raise the feed point voltage enough so that the current returns to its original value. The second, and preferred method, is to add a reactance in series, equal in value but opposite in type (sign) to the reactance value of the antenna. For example, if the antenna at the operating frequency presents an inductive reactance of 100 ohms (+j100) along with a resistance of 50 ohms, inserting a capacitor whose reactance is also 100 ohms (-j100) in series has the effect of cancelling out the reactance of the antenna, leaving only the 50 ohms resistive. This can be looked on as a series R,L,C circuit that is in resonance, whose total impedance is only that of the resistance. Another term for this approach to maximize power transfer is "conjugate impedance matching".

2-24/21

In the above example, we used a value of 50 ohms for the radiation resistance. If this value were not 50 but 150 ohms, the impedance after cancelling the reactance out would be 150 ohms. Connecting this load to the transmitterdesigned to operate with 50 ohms load would not result in optimum power transfer. It would, however, be better than leaving the inductive reactance in, since the antenna current is maximized for the conditions that do exist. To obtain design performance, it is necessary to transform the 150 ohms to 50. This can be done with a transformer with a turns ratio of 1.73 to 1. (Impedance transformation is equal to the square of the turns ratio.) It is also possible to accomplish this transformation with a parallel tuned circuit with primary and secondary taps properly located on the inductor, or using two or more capacitors in series with taps taken from the series string. Under these conditions, the transceiver will deliver rated power to the antenna.

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Briefly, the line characteristic impedance is determined by the physical dimensions of the line -- wire diameter and spacing -- and the dielectric of the material in between. The wire also posseses a resistive component which will dissipate power when current flows through it to the antenna. This shows up as heat loss and dictates use of low loss cable. Formulas for coax and open wire line impedances are given in the handbooks.

Since rf currents flow in the transmission line, one may ask if it then becomes an antenna. In the case of coax type lines, the current should flow on the inside surface of the outer conductor and outer surface of the inner conductor. The electric and magnetic fields caused by the current flow are confined between the two, so none can escape and be radiated. If a system configuration results in some rf current flowing on the outer surface of the outer conductor, such as when a dipole is fed with coax without a balun or other means of changing the feed line from an unbalanced to balanced configuration, it will radiate power. In the case of parallel lines, the current in one conductor at a given location should be flowing in the opposite direction to the current in the adjacent conductor, and if the system is well balanced, the amplitudes of the two will be equal. Under these conditions, the two sets of fields exactly cancel each other and very little radiation will result. If the two currents are not equal or not in exact opposite phase, there will be radiation. Also, if the spacing between lines is a considerable portion of the wavelength, radiation will occur. This is not a factor below VHF.

One final characteristic of transmission lines should be mentioned. The rf current flowing in the line travels at a speed less than that of radiated power in a vacuum, or the speed of light, both 186,000 miles per second. This slowing is caused by the dielectric property of the medium through which the field traverses. In coax cables it is polyethelene between inner and outer conductors, and in parallel lines, it may be the plastic between the conductors in the case of twin-lead type line, or the air and plastic spacers in open wire

types. The ratio of the speed in the line to the speed in a vacuum (air is almost the same) is called the velocity factor of the cable. It is always less than unity. Because of this slowing, the physical length of a transmission line is not the same as the electrical length. For example, the wavelength in free space of a 30 MHz signal is exactly 10 meters. A transmission line 10 meters long will be one full wavelength only if the dielectric between the conductors is air. In the case of coax cable with polyethelene dielectric, the velocity factor runs about 0.67. The same 10 meter length of cable will now appear electrically as an open wire or air dielectric cable 15 meters long (10 divided by 0.67). This is equivalent to one and one half wavelengths. A polyethelene type cable would only have to be 6.7 meters long to be one wavelength.

EFFECT OF TRANSMISSION LINE ON ANTENNA IMPEDANCE - As a result of all of the above, in situations where we do not have a matched system throughout, and this is most of the time, the impedance presented to the transmission line by the antenna sets up standing waves on the line. These standing waves will alter the antenna impedance all along the line toward the transmitter. What we really want to accomplish with the antenna tuner is to take whatever impedance that is established at the transmitter end of the line and alter it to a 50 ohm resistance. Then the transmitter will be happy, at least. The tuner will not affect the mismatch of antenna to line -- only constructing the antenna differently will do that --nor eliminate a standing wave on the transmission line. It will eliminate a standing wave on the line between transmitter and tuner input, but not on the output side of the tuner. A good antenna is still needed to "get out". If the antenna has a low resistance, the tuner will transform it, along with the cable loss resistance, to 50 ohms. The full power will enter the system, but it will be divided between radiation and cable heat loss. It is not uncommon that more than half of the available power is wasted in cable losses, even with low loss cable. It just gets a bit hotter. The split depends entirely on the ratio of radiation resistance to loss resistance.

What is the impedance established at the transmitter end of the line? It depends first on the antenna impedance, which is then transformed by the line. This transformation is dependent on frequency, electrical length of the line and the loss in the line. In an Amateur setup where many different frequencies are used with the same antenna, there will be a multitude of impedances presented to the tuner, so adjustment of the matching network will be required as frequency is changed.

STANDING WAVE RATIO - A measure of how badly a system is mismatched is given by the standing wave ratio (SWR) on the line. SWR is the ratio of the maximum voltage encountered along a transmission line greater than one half wavelength long to the minimum voltage. It is also the ratio of maximum to minimum current. The more nearly uniform the voltage distribution along the line, the closer matched it is, and the ultimate is when the voltage is constant down the length of a lossless line, or drops slowly and uniformly along a line with losses. This is the matched condition, represented by a 1 to 1 SWR. The impedance at the load end of such a line is the same as that at the generator end. When adjusting a matching network properly, the way to do it is to observe the SWR and tune for as low a ratio as possible.

The SWR is also an indication of the value of resistance at the load end. The ratio is the same as the ratio of load resistance to line characteristic impedance. This ratio can mean that the load is either greater than or less than the line's impedance. For example, if the SWR on a length of 50 ohm line is 3 to 1, the load resistance is either 150 ohms or 16.7 ohms (3 times 50 or one third of 50). This is only accurate with pure resistive loads.

It can be shown mathematically that a 2 to 1 SWR in a system which has the transmitter output impedance equal to the line impedance delivers 89% of the power to the load that it would if perfectly matched. This relates to a power loss of half a decibel -- hardly noticeable in signal strength. At a 3 to 1 ratio, the loss becomes appreciable with 25% of the power lost. So in adjusting antenna tuners, it is a nice feeling if you achieve a 1 to 1 match, but in reality, anything below 2 to 1 is satisfactory. Line losses do increase a bit also with increasing SWR, but it is still a small fraction of a dB at 2:1.

TRANSMATCH TUNER CIRCUIT - A look at the schematic reveals that the circuit used in TEN-TEC tuners consists of a parallel circuit of inductor L1 and two variable capacitors connected in series. The input is applied to the center of the series capacitors and ground. Another variable capacitor is connected in series with the output lead to the COAX and SINGLE WIRE terminals. For ballanced outputs, balun L2 is connected so that the basic tuner output is applied to one half of the winding, and transformer action produces the opposite half with reference to chassis ground. Hence the balanced output will provide twice the rf voltage, symetrical to ground. The impedance transformation with this arrangement is a step-up of four times on the antenna side. This circuit should match just about any antenna system impedance to 50 ohms.

When the circuit is tuned for a match, the parallel tuned circuit will be approximately in resonance at the frequency involved. Reactive components in the load will be compensated for by both the series output capacitor and a slight off-resonance setting of the parallel circuit. It will be noted that since both inductor and shunt capacitor are variable, there are many possible settings of these components that will resonate at a given frequency. A high inductance with small capacitance will resonate just as well as a small inductance with large capacitor. Is one way better than the other? The answer is yes. When matching to high impedances, there must be a certain amount of inductance present before a match is achievable. The step up transformation of resistance is dependent on the "Q" of the circuit, which is a function of the inductance. In addition, the frequency range over which operation with acceptable SWR is possible without retuning is dependent on the L to C ratio of the circuit. The smaller this ratio, the greater the bandwidth. (To illustrate how effective this becomes at low frequencies, the following results from lab tests at 3.75 MHz and a 50 ohm load were obtained: With maximum L/C ratio, i.e. INDUCTANCE setting of 47 and SHUNT CAP. about 3.2, the frequency range before a SWR of 2 to 1 was encountered was 50 kHz, $\pm$ 25 kHz on either side of the center frequency. Using the lowest L/C ratio, INDUCTANCE set to 14 and SHUNT CAP. to 10, range increased to over 400 kHz, almost the entire 80 meter band.) With the broader band L/C ratio, tuner adjustments become less critical and the SWR meter dip to 1 to 1 is broad. With high L/C ratios, the dip is very narrow and sharp, and it may be easily overlooked.

To summarize the above: Best and broadest operation is obtained when SHUNT CAP. is set to maximum possible setting that will allow a match to 1 to 1. Under these conditions, INDUCTANCE will be minimum at which resonance can be attained. SERIES CAP. is primarily used when reactive components need cancelling out. With single wire resistive antenna, SERIES CAP. setting will be near maximum.

OVERALL SUMMARY

1.) Any antenna can be represented as an equivalent resistive/reactive impedance whose resistive component, termed radiation resistance, is a measure of the power radiated. Reactance can be either inductive or capacitive.

2.) Antenna impedance is a function of frequency, configuration, selection of feed point location, height above ground and nearness to surrounding objects.

3.) The reactive portion of the impedance does not absorb power but limits the amount of power radiated by the resistive component. It is best to eliminate the reactive component, by inserting an equal value reactance in series, but of the opposite type.

4.) Best system performance is attained when antenna impedance is purely resistive with value equal to transmission line impedance, which in turn equals transmitter output impedance.

5.) Since antennas seldom present matched impedances to line over a band of frequencies and from band to band, a partial solution to using these mismatched systems is to convert the impedances at the transmitter end of the line to what the transmitter is designed for, with an antenna tuner.

6.) The transmission line will change the antenna impedance in both resistive and reactive values at the transmitter end, depending on the line's

electrical length, frequency and characteristic impedance.

7.) Due to slowing down of the current flow in the transmission line from that in free space, the electrical length of a line will be longer than the physical length.

8.) One special situation where the line does not alter the impedance is when its length is an exact multiple of the electrical have wavelength.

9.) An antenna tuner will not affect the antenna impedance nor the standing wave condition on the transmission line. It will correct the SWR on that portion of the line between transmitter output and tuner input, so that the transmitter will supply rated power to the system.

10.) Standing wave ratio, SWR, is a measure of the mis-match of the system and is used as the indicator when making tuner adjustments. SWR is direct ratio ofload resistance to line's characteristic impedance.

11.) SWR other than 1 to 1 indicates two possible impedances, one greater and one less than characteristic impedance.

12.) Any SWR value less than 2 to 1 is considered a good match.

13.) Transmatch tuner circuit can provide a number of different control settings, all of which produce a match. Difference is in L to C ratio of the tuned circuit.

14.) The lowest L/C ratio will provide greatest bandwidth for a given SWR limit. If adjusted for maximum bandwidth, retuning across the band will only be necessary on 160 and 80 meters, and possibly on extremes of 40 meter band.

OPERATION

1.) Always make tuner adjustments with minimum required power from transmitter. To do this, set sensitivity of SWR bridge to maximum, fully CW on Model 277.

2.) Set up meter to read SWR. This is REV. switch position on Model 277.

3.) Set both SERIES CAP. and SHUNT CAP. fully clockwise, (10 position).

4.) Apply just enough drive to transmitter so that meter reading is approximately half scale.

5.) Attempt to find a null as INDUCTANCE control is increased from full CCW position. Null may not be deep at this point. If null is not apparent, reduce setting of SERIES CAP. a bit and try again.

6.) With INDUCTANCE set for best null, try to deepen null with SERIES CAP. If rotating this control CCW from 10 position causes meter deflection to increase, set INDUCTANCE control one step clockwise and try dipping with SHUNT CAP. again. Continue until SHUNT CAP. can provide a null near its full maximum position. Adjust transmitter drive to provide adequate meter deflection.

7.) If null produced is not 1 to 1 with rated drive, decrease setting of SERIES CAP. a bit and renull with SHUNT CAP. Continue this procedure until 1 to 1 reading is obtained with full drive, or best null below 2 to 1 is attained. (If by decreasing SERIES CAP. resonance is not attainable with SHUNT CAP., increase INDUCTANCE one more notch and retune capacitors.

8.) To accurately determine if SWR is sufficientle low, set FWD. meter deflection to indexed mark on meter with SENSITIVITY control and read SWR in REV. switch position. Reading below 2 is acceptable.

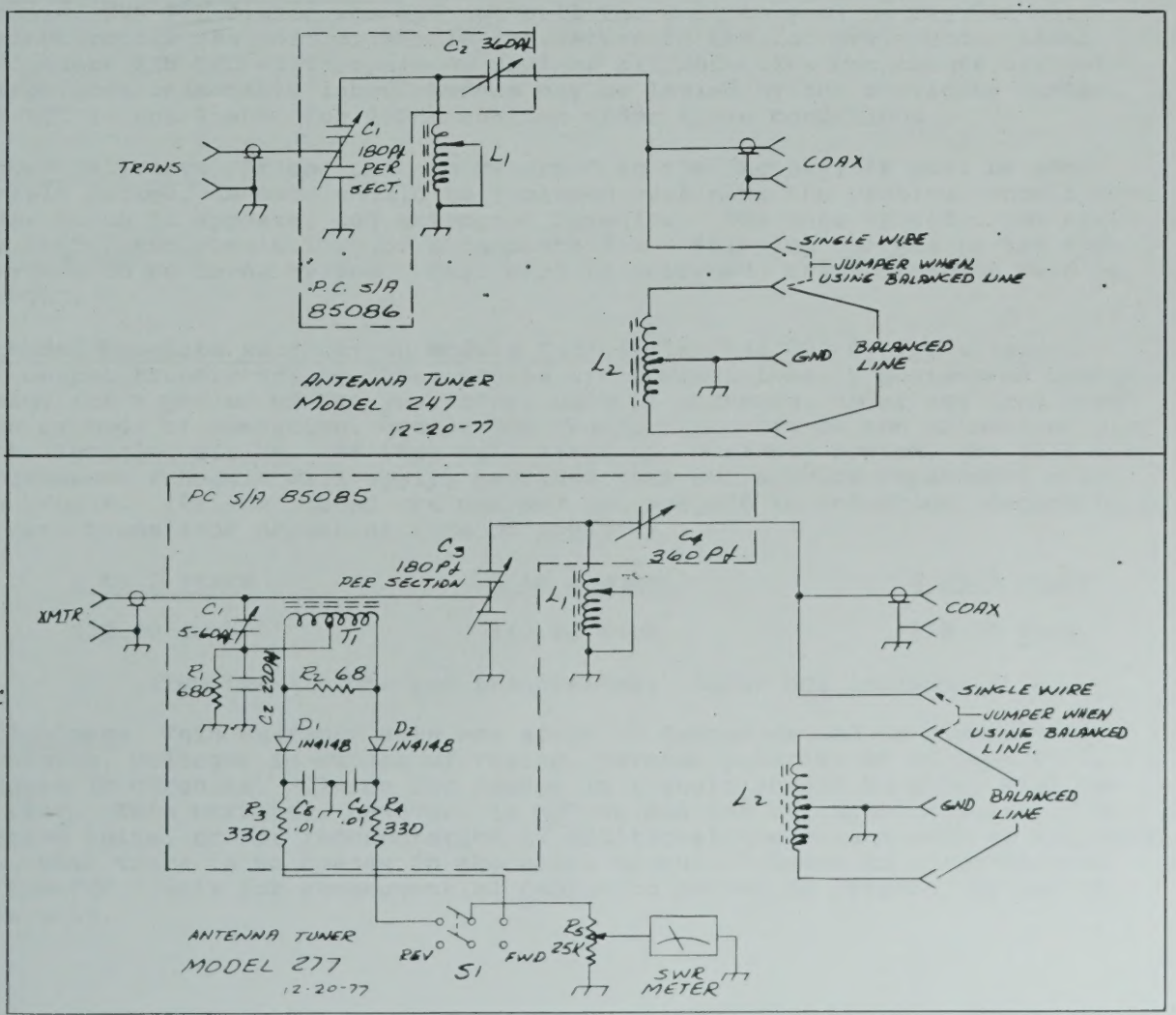
9.) It is good procedure to leave SWR meter in REV. position so that you can monitor match while operating. If you tune too far from resonance, it will be apparent and retuning can be initiated.

10.) It is convenient to record control settings for each band of operation and possibly at 3.6 and 3.9 MHz of 80 meter band. Then tune-up will be simplified when changing bands because starting points will already be established.

Approximate starting points for control settings for each band are given in Table I below. These guideline settings require some alteration for your specific antenna systems, and exact settings should be determined using the procedures outlined above. Reactive loads will alter the values somewhat, but mainly in the SERIES CAP. columns.

TABLE I
GUIDELINE CONTROL SETTINGS

FREQ. MHz	UNBALANCED COAXIAL FEED SYSTEMS									SINGLE WIRE			BALANCED LINE		
	50 OHMS			150 OHMS			17 OHMS			800 OHMS			300 OHMS		
	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.	SERIES	SHUNT	IND.
1.8	7	10	38	7	10	44	10	10	29	-	-	-	8	10	34
3.6	7	10	15	7	10	17	9	10	11	10	10	23	6	10	16
3.9	7	10	13	7	10	15	9	10	10	10	10	21	6	10	14
7.1	6	10	6	7	9	7	7	10	5	10	7	12	5	10	7
14.2	4	9	3	6	7	3	4	10	2	10	5	6	4	10	3
21.2	2	8	2	5	9	1	1	7	2	10	3	4	3	7	2
28.5	1	7	1	2	5	1	0	9	1	10	2	3	3	7	1



TEN-TEC, INC.
Sevierville, TN 37862

REPAIR DEPARTMENT TELEPHONE
615-428-0364

LIMITED WARRANTY AND SERVICE POLICY

TEN-TEC, INC. warrants all products to be free from defects in material and workmanship for a period of one year after date of purchase, under these conditions:

1.) Registration: The warranty card must be returned promptly to establish the warranty period. Our card file also serves as a check on stolen equipment which may be sent in for repair. Please notify us immediately if your TEN-TEC equpment is stolen.

2.) Original Purchaser: This warranty applies only to the original purchaser. Your returned warranty card listing from whom purchased establishes you as the original purchaser.

3.) Communication with the Factory: If trouble develops, contact your TEN-TEC dealer from whom you purchased the unit. He is obligated to try to correct the malfunction or return the unit to us. If he is unable to correct the fault, you or the dealer should contact the factory by mail or by telephone 615-428-0364, giving serial number if assigned, symptoms of fault and conditions under which they appear. You will be advised whether to return the unit to us or to try a replacement plug-in assembly that will be sent to you. To facilitate service calls, please use our direct Repair Department telephone number, 615-428-0364. (NO COLLECT CALLS, PLEASE.)

4.) In-Warranty Field Repairs: To expedite repairs TEN-TEC will send replacement assemblies prior to receiving the suspected defective one from you. The replacement will be billed on a 30 day memo, and credit will be issued when the defective unit is returned to us. No remittance or deposit is required. If the defective assembly is not returned within 30 days, you will be billed.

5.) Return to Non-Selling Dealer: If you return the in-warranty unit to an authorized TEN-TEC dealer who did not sell the unit to you, he may, at his option, repair the unit or handle the return to the factory. Under these conditions TEN-TEC will repair or replace all defective components without charge, but reasonable labor charges may be levied by the servicing dealer. TEN-TEC is not liable for labor charges under these conditions.

6.) Proper Delivery: If the unit is returned to the factory, it must be adequately packed. A note should be included outlining the problem, conditions under which it appears, and attempted remedies. The more specific you are, the better the possibility of a complete fix. Shipping charges to the factory are to be borne by you. Unit will be returned, transportation paid by TEN-TEC.

7.) Extended Pro-Rata Warranty on Models 540/544/545/546 Output Transistors: The output transistors on these models are unconditionally guaranteed against damage for a period of one year after date of purchase, under any load condition or mode of operation, except for static discharge on the antenna or direct lightning strike. If they fail after the warranty period, the following replacement schedule will apply, provided that our service department makes the repair. (Prices listed are maximum and subject to reduction, depending on current transistor prices at time of repair.)

1 to 2 years	2 to 3 years	3 to 5 years
$12.00 each	$15.00 each	$18.00 each

(Two transistors per transceiver. Labor not included.)

8.) Exclusions: This warranty does not apply to damage caused by mishandling, lightning, voltages in excess of rating, reverse polarity of DC supply, or changes in circuits. Claims for damage in transit should be filed with the carrier. This warranty, however, is NOT voided for attempted repairs of defective units, or for incorporation of additional components such as switches, etc. when there is no change in the basic circuit. Under no circumstances is TEN-TEC liable for consequential damage to person or property by use of this unit.

9.) TEN-TEC reserves the right to make any improvements to its products which it may deem desirable without obligating itself to install such improvements in its previously manufactured products.

10.) This warranty is given in lieu of any other warranty expressed or implied.

Out-of-Warranty Repairs

1.) Field Repairs: New circuit boards or discrete components can often be supplied to eliminate the cost and bother of shipping the complete unit to us. A nominal charge will be made for the material sent. Certain assemblies intregal with the main chassis, such as VFO assemblies and rack tuning mechanisms, are not field replaceable.

2.) Returned Units: Along with the unit, please submit a complete report on the nature of the malfunction and the conditions under which it occurs. This will enable our service department to pay special attention to your problem area and reduce overall labor costs. No matter what the malfunction is, every unit will be given a complete alignment and operational check before being returned.

3.) Quotations: Quotations on repair work will be given on request, after examination of the unit. The amount quoted will be firm for the specific work outlined in the quotation. Should additional material or labor requirements come to light after the repair is initiated, you will be contacted for approval before this phase of the repair is started.

4.) Repair Charge Payment: Charges below the $25.00 level will be billed to you after completion of the work and at the time of re-shipment. A report of all work done and parts used will accompany the bill. For charges greater than $25.00, prepayment will be required before the unit is returned. One of three methods of payment may be selected. 1.) Upon completion of the work the billing will be made but the unit will be held here. Upon receipt of the payment, the unit will be shipped. 2.) The unit will be returned to you on a COD basis, with COD charges borne by you. 3.) The repair charges may be paid by either MasterCharge or BankAmericard/VISA.

Approval for COD or charge card options can be given either at the time the unit is submitted to us (in the accompanying letter) or when contacted upon completion of the repair. Please submit all raised information on your charge card when paying by this means.

5.) Transportation Charges: Units should be returned, transportation and insurance charges prepaid. Return transportation and insurance charges will be billed to you with other costs.